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SALYUT

SOVIET STEPS TOWARD PERMANENT HUMAN PRESENCE IN SPACE

A TECHNICAL MEMORANDUM

DECEMBER 1983

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CONGRESS OF THE UNITED STATES
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Foreword

As the other major spacefaring nation, the Soviet Union is a subject of interest to the American people and Congress in their deliberations concerning the future of U.S. space activities. In the course of an assessment of Civilian Space Stations, the Office of Technology Assessment (OTA) has undertaken a study of the presence of Soviets in space and their Salyut space stations, in order to provide Congress with an informed view of Soviet capabilities and intentions.

The major element in this technical memorandum was a workshop held at OTA in December 1982: it was the first occasion when a significant number of experts in this area of Soviet space activities had met for extended unclassified discussion. As a result of the workshop, OTA prepared this technical memorandum, "Salyut: Soviet Steps Toward Permanent Human Presence in Space." It has been reviewed extensively by workshop participants and others familiar with Soviet space activities.

Also in December 1982, OTA wrote to the U.S.S.R.'s Ambassador to the United States Anatoliy Dobrynin, requesting any information concerning present and future Soviet space activities that the Soviet Union judged could be of value to the OTA assessment of civilian space stations. The result of this request is appendix A of this technical memorandum: "The Soviet Salyut Space Program: Space Station, Spacecraft, Support, and Training Facilities" is an official summary of Salyut space station activities, provided to OTA by Dr. Balayan, Vice-Chairman of the Intercosmos Council of the U.S.S.R.'s Academy of Sciences. OTA appreciates the cooperation of Ambassador Dobrynin and the Soviet Academy in providing this information. This appendix is of particular interest in that such information is seldom provided to American agencies through official Soviet channels.

Appendix B is a paper prepared for OTA by Geoffrey E. Perry, head of the Kettering Group in England. This paper, "Soviet Space Stations: Achievements, Trends, and Outlook," provides an independent view of Soviet accomplishments in this area; it is based, in part, on the Kettering Group's long-term monitoring of audio communications between the Salyuts and Soviet ground stations.

Those individuals acknowledged in appendix C provided information during the course of the study and/or reviewed the draft report.

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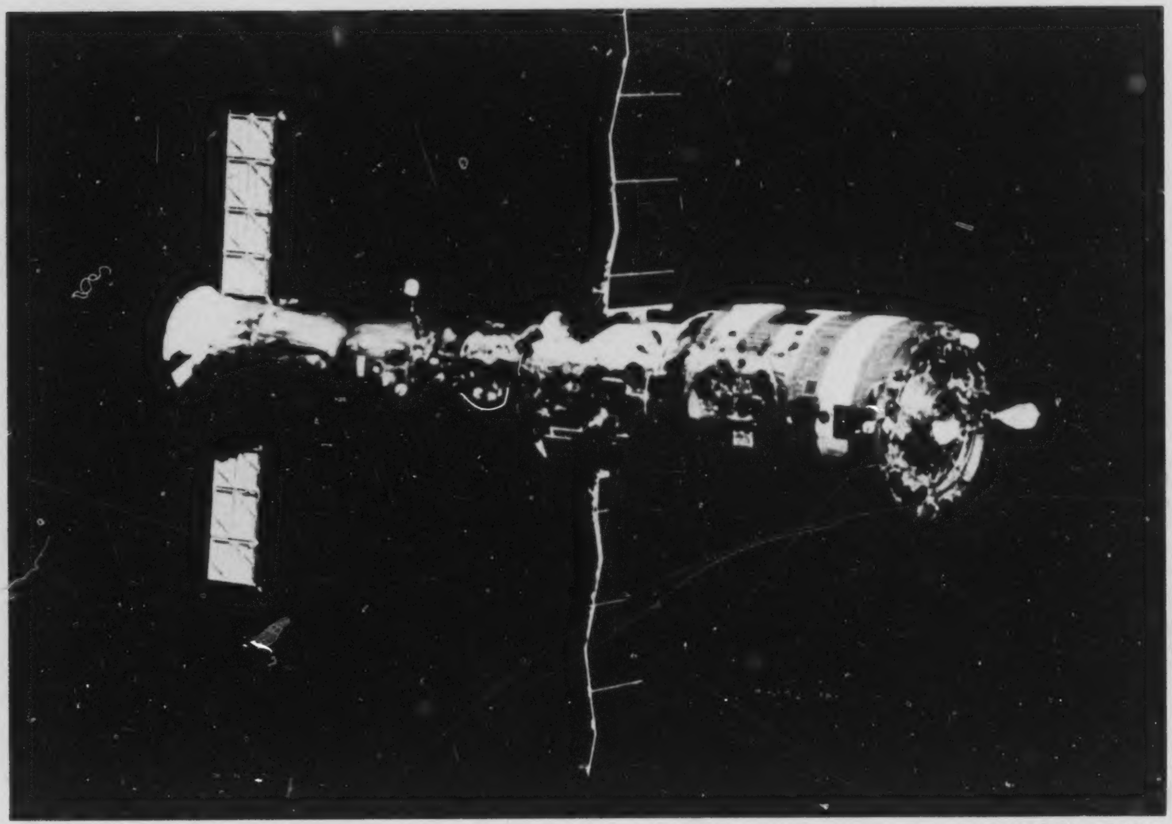

Photo credit: Tass

Orbiting complex Salyut 7—Soyuz T-5 (photo taken from Soyuz T-6 on July 2, 1982, from a distance of about 120 m)

Introduction

A number of citizens of the Soviet Union, and their guests from other countries, have visited the Earth's lower space regime; the Soviet in-orbit space infrastructure, primarily the Salyut space stations (or, as the Soviets say, "orbital stations"), has housed and supplied them there, more or less continuously, for over a dozen years. During this period the total number of hours that Soviet cosmonauts have spent in space has overtaken and is now much greater than the corresponding total for U.S. astronauts. By all accounts, the Soviets are more knowledgeable than the United States in space biology and medicine; in a number of technical areas, notably in the use of automated docking systems, they routinely use techniques that the United States has never demonstrated. It is true, on the other hand, that the Space Shuttle now gives the United States significant capabilities that the Soviets do not have, but it is widely believed on the basis of photographic evidence available from unclassified sources that the Soviet Union is developing both a small space plane and a heavy-lift shuttle expected to be capable of propelling more massive payloads into low-Earth orbit than can its U.S. counterpart.

The Soviet space station program is the cornerstone of an official policy which looks not only toward a permanent Soviet human presence in low-Earth orbit but also toward permanent Soviet settlement of their people on the Moon and Mars. The Soviets take quite seriously the possibility that large numbers of their citizens will one day live in space. Although the Soviets do not often directly communicate detailed results of what has been learned by and from the cosmonauts aboard Salyuts, enough information is available to conclude that they are accomplishing much more than rudimentary scientific investigations: they are providing the data, information, and experience required to design habitats and equipment which will allow individuals to reside for the long-term in space.

The Soviet approach to the development of space capabilities differs significantly from the American. Whereas the United States tends to advance from one space capability to the next by quantum leaps, the Soviet Union tends to modify and adapt technology that is already in hand, thereby increasing its capability in a seemingly more evolutionary or progressive fashion. By thus relying on systems flight-proved in earlier space programs, the Soviets may have been able to restrain costs and minimize the time spent in development and construction. The Soviet space program and the U.S. satellite communications industry are similar in that both allow for the establishment of gradually evolving spacecraft design, and it may be advisable for the United States, in other selected areas of space applications, for example, to adopt some form of the Soviet strategy. Already, NASA's Solar System Exploration Committee (SSEC), emphasizing the importance of system heritability, has advocated a similar approach for planetary science.

The relative merits of automated and human capabilities for performing work in space or, more precisely, the criteria for establishing the optimal mix of the automation and the human presence for particular tasks, are the subjects of considerable debate in the United States. Although the amount of time in space that American astronauts have amassed is nontrivial, there is a certain degree of unreality about this debate because it cannot yet be grounded in extensive experience. The Soviet Union, on the other hand, can draw on a much greater fund of experience as they implement plans for integrating human and machine capabilities for work on future space stations.

Perhaps the most important point to be made here is that the United States and the Soviet Union have cast the issue of humans versus machines in different terms. U.S. space policy is to explore and study space and to use it for general human benefit—and, where appropriate, to involve human beings in actual spaceflight. In addition, both the United States and the Soviet Union use their spaceflight programs involving people to enhance their national images. Soviet space policy, however, goes further; it includes the goal of learning how human beings may reside permanently in space, both as an end in itself and as a means of serving their national purposes. To date, the United States has not committed itself to permanent human occupancy of space as a national goal.

Executive Summary

The launching of Sputnik 1 initiated a space race that led to the landing of astronauts on the Moon; today the United States and the Soviet Union are well aware of their relative strengths and weaknesses in space activity. In most areas of space science and space applications—best exemplified, respectively, by the Voyager missions to Jupiter and Saturn, and the burgeoning satellite communications industry—the United States, through steady, long-term effort, seems to have gained a substantial lead over the Soviet Union.

In human spaceflight, the picture is less clear because the countries have taken quite different approaches. In some respects, the activities of the two countries in this arena have resembled the race between the tortoise and the hare: while the Soviet effort has featured apparently steady, incremental progression along well-defined lines of development, the United States has typically played catchup, using its strong technological capacity to produce space achievements of startling virtuosity. Continuing development on both sides has been fueled by a combination of political, economic, and military motives, in different order of importance at different times.

The divergent approaches of the two countries have led to two very different types of current human spaceflight capability. The Soviet Union has, since 1971, pursued a more-or-less continuous program of development of space stations in low-Earth orbit (LEO). With the sixth operational model of the Salyut series now flying, Soviet cosmonauts have logged over three times the U.S. total of crew-hours in space, and accumulated extensive experience in the conduct of flight operations, experimentation, and Earth observation in trips that last for months. However, they are currently restricted to the use of relatively small, expendable launch vehicles for crew transportation and resupply. The United States, on the other hand, has an operational space Shuttle which permits the routine ferrying of crews and large payloads into orbit for over a week, currently at the rate of some 5-6 flights per year. The Shuttle is reusable, its staytime in orbit could be increased, and the planned fleet of four Orbiters could provide staytime on the order of months per year. But an individual unmodified Orbiter does not provide a habitation combining large volume, high power, and long duration needed for many of the in-orbit research and development activities of interest, particularly to the life sciences and some in the private sector.

The National Aeronautics and Space Administration is now considering "the next logical step" for its space program: the establishment of a potentially permanent human presence as part of an actually permanent LEO infrastructure, i.e., what NASA describes as a civilian space station. If the administration formally proposes to begin work on such infrastructure, then Congress may find that a detailed examination of the Soviet human presence in space, the Salyut space stations, and their associated space vehicles, can provide a useful frame of reference.

Early in this century, Konstantin Tsiolkovsky, a Russian scientist and engineer, provided the theoretical underpinnings for the Soviet space program with his visionary writings about the use of orbiting stations as a springboard for exploring the cosmos. One can still find the influence of his theories in the statements of modern-day Soviet leaders.

But Soviet scientists and technicians have found that the road to realizing their dream is a long and difficult one. After initial successes with Sputnik and the early orbital flights of cosmonauts in the one-seat Vostok capsule, the Soviet space program began to feel the limitations of its technology. The 6-metric-ton (tonne; one tonne = 2205 lbs) Voskhod flew only twice, Voskhod 1 with three crewmembers, Vockhod 2 with two. Two years later, in 1967, a new space vehicle debuted with Soyuz 1. Despite the death of the first Soyuz pilot in a crash landing, the Soyuz-class ship eventually became the principal means of putting cosmonauts into space. After 12 years of Soyuz operations, a new design, Soyuz T, made its inaugural flight in 1979.

In the late 1960's, the Soviets appeared to be intent on sending cosmonauts to the Moon, but, in view of the success of the U.S. effort to do so, they eventually settled for landing automated probes on the lunar surface. Subsequently, the focus of the Soviet manned space program shifted exclusively to the establishment of a strong capability for near-Earth orbital operations, i.e., the development of space stations and associated space vehicles. When Soyuz 4 docked with its sister ship Soyuz 5 in January 1969, the Soviets called the resulting complex "the world's first space station," although the two craft had no connecting passageway between them. Salyut 1, which provided one continuous volume capable of supporting human habitation for time-periods of the order of months, went into orbit in 1971; the most recent of the series, Salyut 7, was launched in 1982 and remains operational today.

Some of the Salyut stations were apparently military in function; others seem to have been primarily civil. With Salyut 6 and 7, the distinction became blurred; it may be that the military no longer has a separate Salyut program. The Soviets have maintained total secrecy in military operations, but they have gradually become more open with their civilian programs, broadening the makeup of their crews to include members from Eastern Europe and other Soviet-bloc countries, France, and, soon, India. Although any joint U.S.-Soviet effort (e.g., the symbolic joining of the Apollo and Soyuz in orbit in 1975) currently seems unlikely, future Soviet missions will probably continue to be international to some degree.

The fact that the Soviet technological base remains relatively narrow seems to be closely coupled with the infrequency with which rapid innovation is achieved, both in Soviet industry generally and in the Soviet space program in particular. Although Soviet spacecraft designers rely heavily on automated control with cosmonauts as backups, crewmembers have, in many instances, assumed broader duties to make up for failures in automation. In any case, Salyut has afforded its crews of engineers and cosmonauts extensive experience in conducting operations in space. Precisely how this experience will be put to use in future operations is unclear.

Salyut may be the penultimate step leading to a permanent, large-scale human presence in space. Before that can be accomplished, the Soviets may have to achieve success in developing a heavy-lift launcher, similar to the U.S. Saturn V, which would allow for the construction of a second-generation station out of much larger modules. A vehicle along the lines of the U.S. space shuttle to provide routine access to a near-Earth station would also be desirable, and indeed Western sources believe that the Soviets may be developing a heavy-lift, reusable shuttle that could carry twice the payload of the American craft. In addition, the Soviets have already conducted tests for a 1-tonne prototype of a 10- to 20-tonne space plane.

With such spacecraft in their fleet, the Soviets would possess both a "space truck" and a light-duty ferry vehicle to provide routine service to an expandable infrastructure in space. With this infrastructure as a hub of operations, extension of human activity to geostationary orbit, the Moon, and even Mars becomes technically feasible—indeed Soviet planners have frequently mentioned each of these as an objective. That previous U.S.S.R. efforts to reach Mars have met with failure may, in the near term, have militated against their initiating programs to send vehicles to the outer planets and deep space. But it is unlikely that the Soviets see these failures as anything more than temporary setbacks, especially in view of U.S. success in planetary exploration generally and their own success in the very difficult task of returning data from the surface of Venus—a feat that the United States has yet to match. Indeed, a Salyut space station may provide the core element of a future base necessary to ensure success of future trips to Mars.

Early Soviet Manned Spaceflight

Historical Background

A central element in the Soviet Union's exploration and exploitation of space has been its reliance on Salyut-class orbital stations occupied by cosmonauts. Seven of these stations have been officially announced by the U.S.S.R. as of December 1983. These facilities have begun to realize the possibilities envisioned by Konstantin Tsiolkovsky, the Russian scientist/engineer who is considered the founder of Soviet astronautics. Early in the century, he described how orbital stations might be built, noting that they represented the very heart of a program of space conquest.

Typical of his observations is this 1923 description of the construction of a system of Earth-orbiting stations:

> We take off in a space ship . . . and stay at a distance of 2000-3000 versts [each verst equaling 0.6629 mile] from Earth, as its Moon. Little by little appear colonies with implements, materials, machines, and structures brought from Earth. Gradually, independent production, though limited at first, will develop.[1]

Reinforcing the conviction of Tsiolkovsky, the late Leonid Brezhnev, then President of the Soviet Union, remarked in 1978:

> Mankind will not forever remain on Earth, but in the pursuit of light and space will first timidly emerge from the bounds of the atmosphere, and then advance until he has conquered the whole of circumsolar space. We believe that permanently manned space stations with interchangeable crews will be mankind's pathway into the universe.[2]

As the launch of Sputnik 1—the Earth's first artificial satellite, on October 4, 1957—opened the path toward realization of Tsiolkovsky's visions, so the Soviet Union's increasing ability to transport people into space in the 1960's, 1970's, and 1980's has added substance to Brezhnev's declaration. At least since the early 1970's, the Soviet Union seems to have taken a slow, more-or-less steady approach toward fulfilling the aspirations of its engineers and political leaders.*

Vostok

Vostok (meaning "East"), a one-seater spacecraft, was the first Soviet vehicle to carry a cosmonaut into orbit.** Six Vostoks were launched between April 1961 and June 1963; they remained in orbit for periods ranging from 108 minutes to nearly 5 days. Weighing 4.7 metric tons (tonnes) and simple in design, the vehicle consisted of two modules: an almost spherical capsule which carried the cosmonaut, and an equipment package containing fuel, life-support gear, batteries, attitude-control thrusters, and a retrorocket to slow the vehicle for reentry into the Earth's atmosphere.

Vostok's pilot was little more than a passenger. With no orbital maneuvering capability designed into the system, the pilot had few responsibilities for control of the spacecraft.

On two occasions, pairs of Vostoks flew concurrently. Two A-1 vehicles launched Vostoks 3 and 4 from the same cosmodrome within 24 hours;*** Vostoks 5 and 6 were similarly launched within 48 hours. In the second case, the Soviets showed they could launch at precise times. In 1962 and 1963, the U.S. manned spaceflight program could not match this achievement, the Mercury program being plagued by a series of "holds" and postponements.

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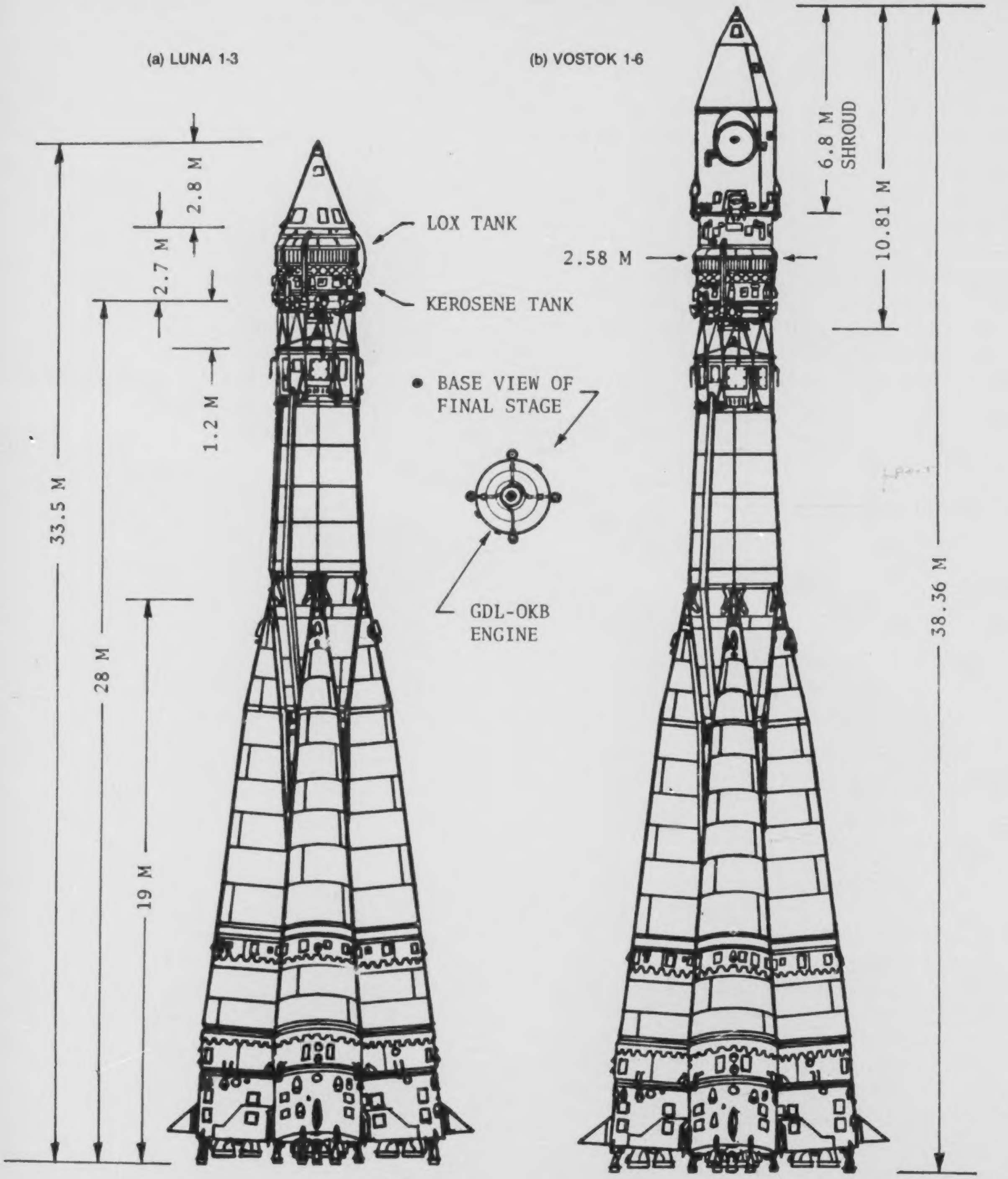
[1] K. E. Tsiolkovsky, *Collected Works*, vol. 2, Moscow, Izdatel'stvo AN U.S.S.R., 1954.

[2] Kenneth Gatland, chief author, *The Illustrated Encyclopedia of Space Technology* (London: Salamander Books, Ltd., 1981), p. 214.

*Many informed Western observers, as well as official Soviet historians and publicists, would extend this characterization to the early years of the Soviet program. Others, however, disagree, arguing that, especially in these early years, the appearance of an evolutionary course disguises a number of false starts, midcourse corrections, and radical changes of plan.

**In preparation for the first manned flight, the Soviets, in 1960 and 1961, launched at least four Sputniks with animals aboard in order to determine how they were affected by the operation of various spacecraft subsystems. These included the launch system, onboard life support and environmental control, and the reentry and recovery system.

***The designations "A," "D," "G," etc., are based on an alphanumeric classification system devised by the late Charles Sheldon of the Library of Congress. Another system designates the launch vehicle with an "SL" and a number. Thus, the "A-2" vehicle is the same as the "SL-4."



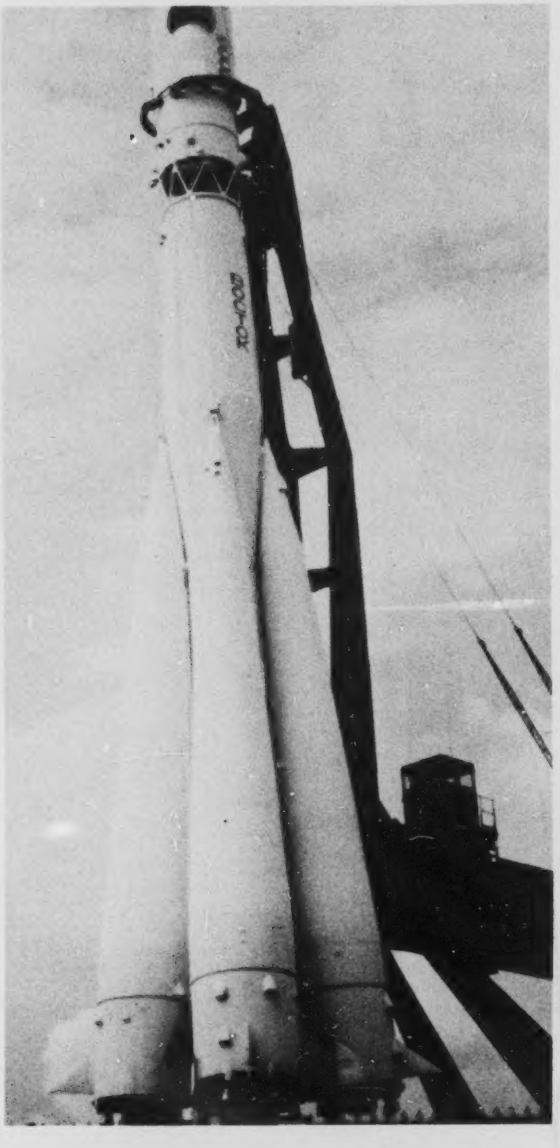
(a) LUNA 1-3

(b) VOSTOK 1-6

2.8 M
2.7 M
1.2 M
33.5 M
28 M
19 M
LOX TANK
KEROSENE TANK
● BASE VIEW OF FINAL STAGE
GDL-OKB ENGINE
2.58 M
6.8 M SHROUD
10.81 M
38.36 M

Credit: ©C. P. Vick, 1982

Luna 1-3 (a); Vostok 1-6 (b)—standard launch vehicle with the first type of added upper stage A-1 (a) as used to launch the first three Luna spacecraft; (b) as used to launch the six Vostok manned spacecraft



Vostok Booster

These simultaneous flights not only served as tests of ground control and launch turnaround capability, but also, as precursors of future rendezvous and docking missions, allowed a determination of how closely spacecraft could be positioned in orbit without specific orbital maneuvers. The orbital injections were so accurate that the first pair coorbited and the second passed within 5 miles of each other in noncoplanar orbits.* With these Vostok missions, the Soviets also demonstrated the capability to handle communications with two spacecraft simultaneously.

Another highlight of the Vostok program took place in June 1963 when Valentina Tereshkova became the first woman in space. Flying in Vostok 6 for 48 orbits around the Earth, she tallied more flight time than all the male astronauts in the U.S. Mercury program. Although relatively untrained and rumored to have been ill throughout her flight, Tereshkova at least achieved substantial publicity.

Voskhod

In October 1964 and March 1965, the Soviet Union launched the 6-tonne Voskhod ("Sunrise"), a modified Vostok capable of carrying two or three cosmonauts on daylong flights. Because the Voskhod was used only for these two flights, some Western experts believe it was intended primarily to preempt the U.S. Gemini program, which would put two astronauts in one vehicle, one of whom would "walk" in space. Voskhod had approximately the same pressurized volume as did Vostok, but more volume was made available for habitable crew space because the ejection seat and rails were removed and because the crew wore overalls instead of bulky pressurized space suits.

Voskhod 1, weighing 5.3 tonnes, had a three-person crew. In Voskhod 2, which weighed 5.7 tonnes, one of the crew couches was replaced with an inflatable airlock and associated hatches to allow for extravehicular activity (EVA), or "spacewalking." During the flight one of the crew accomplished the first spacewalk of some 10 minutes duration.** The Voskhod program included the first flight of a physician to conduct in situ observations; it also tested new TV and audio communications equipment, evaluated techniques for spacecraft orientation, and employed a new solid-rocket, soft-landing system. It did not, however,

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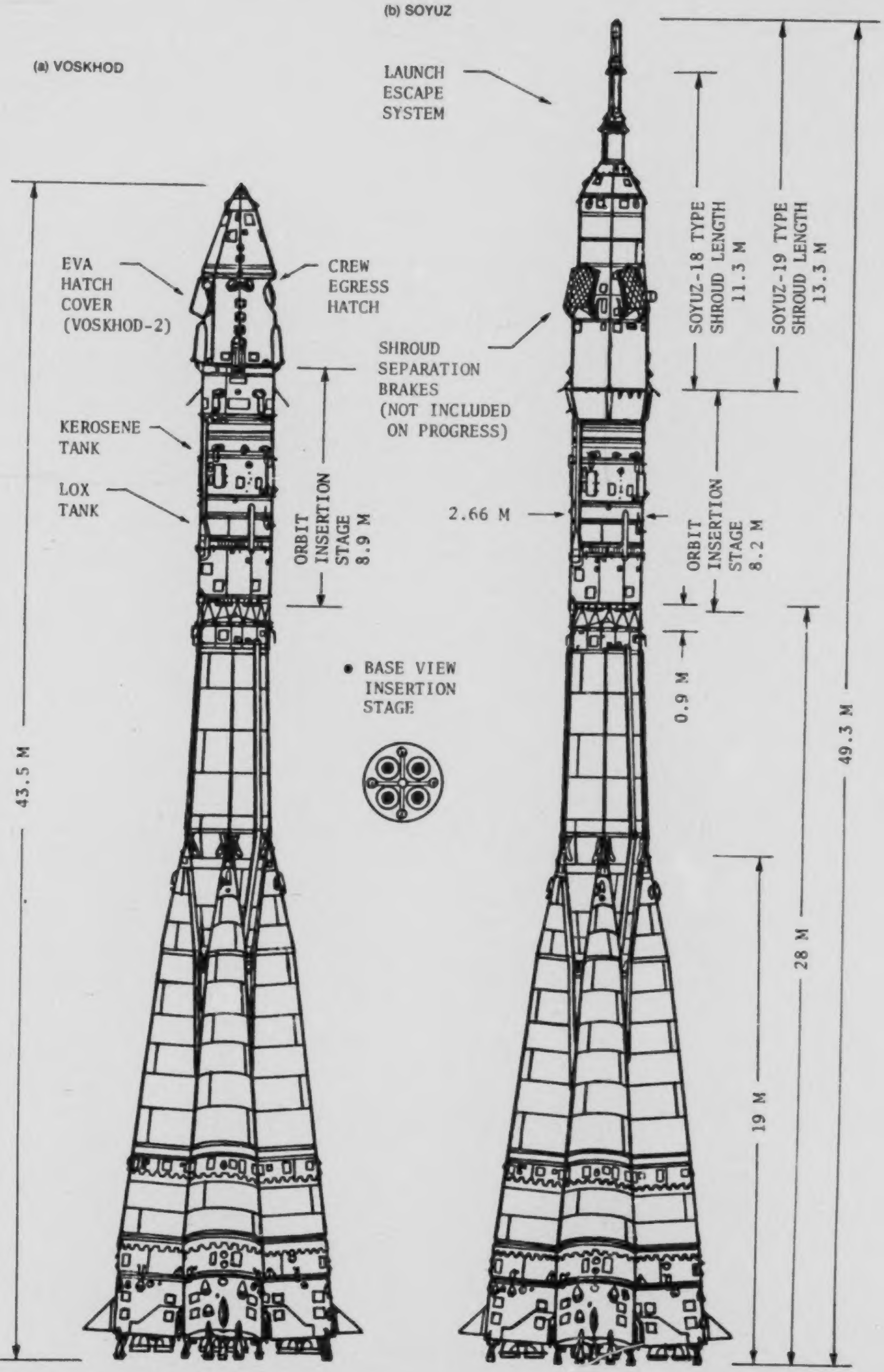
*The orbits of Vostok 5 and 6 were in fact separated by almost 29° at their point of nearest approach, with the result that their relative velocity was approximately 12,000 feet per second. This hardly could be counted as a rendezvous.

**The cosmonaut spent a total of some 22 minutes under space conditions—12 minutes outside the spacecraft, and the preceding 10 minutes in a depressurized, inflatable airlock.


(a) VOSKHOD
(b) SOYUZ
LAUNCH ESCAPE SYSTEM
EVA HATCH COVER (VOSKHOD-2)
CREW EGRESS HATCH
SHROUD SEPARATION BRAKES (NOT INCLUDED ON PROGRESS)
KEROSENE TANK
LOX TANK
ORBIT INSERTION STAGE 8.9 M
2.66 M
ORBIT INSERTION STAGE 8.2 M
SOYUZ-18 TYPE SHROUD LENGTH 11.3 M
SOYUZ-19 TYPE SHROUD LENGTH 13.3 M
BASE VIEW INSERTION STAGE
43.5 M
0.9 M
49.3 M
28 M
19 M

Credit: ©C. P. Vick, 1982

Voskhod-2 (a); Soyuz T (b)—standard launch vehicle with the improved upper stage A-2 (a) as used to launch the two Voskhod manned spacecraft; (b) as used to launch the Soyuz T manned spacecraft include a launch escape system. As the first of a series of individually small but cumulatively significant advances in Soviet space capabilities, the Voskhod program brought the Soviet Union's total person-hours in orbit to some 507; by contrast, U.S. astronauts had accumulated 53 hours through Project Mercury.

By the end of the Voskhod program, the Soviet Union was dedicating its engineering expertise to the creation of a more capable spacecraft—the Soyuz ("Union"). During the 2-year hiatus between the flight of Voskhod 2 and Soyuz 1, the U.S. Gemini program of 10 flights accomplished many outstanding first-time achievements; American crewmembers also overtook their Soviet counterparts in flight time, a lead they maintained, through the Apollo-Soyuz Test Project (ASTP) in 1975, until the flight of Soyuz 29 in June 1978. The Salyut 6 missions subsequently reestablished the Soviet lead, more than double the U.S. total.

Soyuz

Building on the technical foundation laid by Vostok and Voskhod, the Soviet Union developed the Soyuz space vehicle. First flown with a pilot aboard in 1967,* Soyuz, the first of the Soviets' truly operational spacecraft rated to carry crew, remains, with evolutionary modifications, the standard vehicle for transporting crewmembers to Salyut ("Salute") space stations. The current design, called Soyuz T, was introduced in 1979. Many Western observers believe that Soyuz was initially developed to serve as part of an ambitious program to send a cosmonaut to the Moon. However, it experienced a number of technical problems, including the inability of the A-2 booster to launch a fully fueled and instrumented spacecraft, launch failures of the medium-lift Proton type D-1-e and the heavy-lift G-class boosters,** and troubles with control systems aboard automated lunar spacecraft. These problems made it impossible to use Soyuz for a manned lunar mission during the late 1960's, when beating the United States to the Moon was, presumably, of high priority. As a result, the Soviets appear to have postponed any such lunar missions indefinitely.

Why were such technical problems not overcome? The conventional explanation holds that the American lunar landings undermined the Soviets' incentive for, and interest in, putting a cosmonaut on the Moon. A fuller appraisal holds that, after Apollo 11, the planned Soviet program would have seemed second rate. The Soviets originally envisioned sending (only) one cosmonaut in a Zond spacecraft to loop once around the Moon (not to make multiple orbits) and probably required an Earth-orbit rendezvous. But the success of Apollo 8 at Christmas 1968 and subsequent near-perfect flights of Apollos 9, 10, and 11, apparently convinced the Soviets to concentrate on other activities. As alternatives that could be achieved, near-Earth, orbiting stations capable of human habitation, and automated probes for lunar sample return (via the Luna series spacecraft) and surface exploration (via Lunokhod 1 and 2) became the new foci of Soviet activities.

Carrying crews of one to three persons, Soyuz has been used to conduct a wide variety of military and scientific experiments. These vehicles are capable of orbital maneuvering, rendezvous and docking, and solo flights with crew aboard for up to 30 days.*

Soyuz is 7 meters in length, 2.7 meters in diameter, and up to 6.8 tonnes in weight, and contains three connected elements that are interdependent for power, thermal control, and propulsion:

- *Command Module.*—Serves as the ascent and descent compartment in which cosmonauts are ferried to and from orbit, as well as the module in which they are stationed during orbital maneuvers. It also contains system function indicators and control panels through which the cosmonauts interact with various automatic systems. The Command Module and the Orbital Work Module to-

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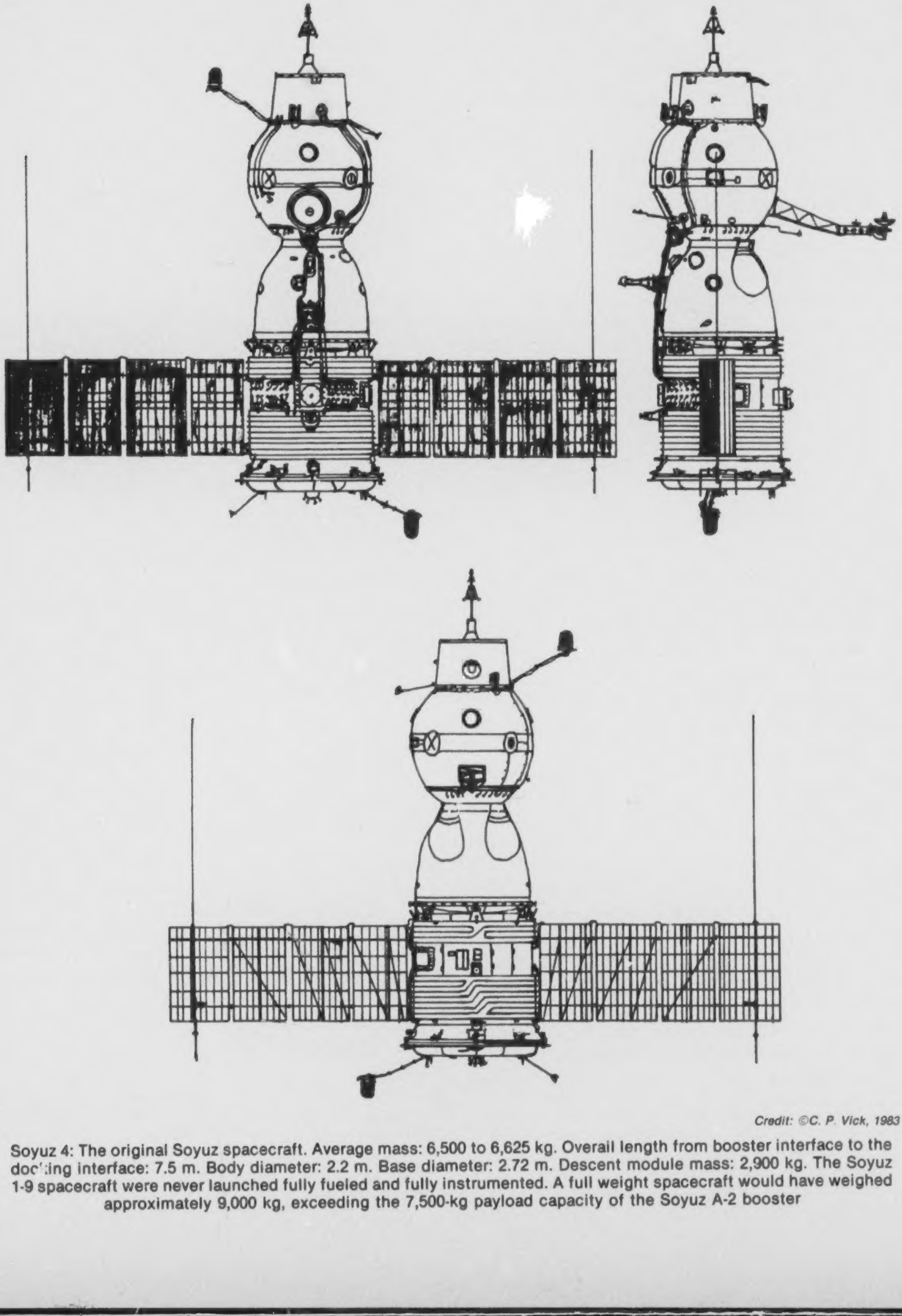
*The first flight of the Soyuz in 1967, ended with the death of the pilot in a crash landing; this kind of craft was not flown again until October 1968.

**The G-series booster is comparable to the U.S. Saturn V vehicle.

*Although 18 days is the longest demonstrated flight of a Soyuz craft with crew aboard, the Soviets have repeatedly stated this time could be extended to 30 days. Without crew aboard, Soyuz vehicles are capable of much longer duration in orbit: Soyuz T-1 recorded a flight of 100 days while docked with Salyut 6; Cosmos 613, undocked, remained in orbit for 60 days.



Credit: ©C. P. Vick, 1983

Soyuz 4: The original Soyuz spacecraft. Average mass: 6,500 to 6,625 kg. Overall length from booster interface to the docking interface: 7.5 m. Body diameter: 2.2 m. Base diameter: 2.72 m. Descent module mass: 2,900 kg. The Soyuz 1-9 spacecraft were never launched fully fueled and fully instrumented. A full weight spacecraft would have weighed approximately 9,000 kg, exceeding the 7,500-kg payload capacity of the Soyuz A-2 booster gether provide a total habitable volume of nearly 9 cubic meters (one cubic meter = 35 cubic feet), roughly twice that of Vostok; in Soyuz T the habitable volume has been increased to about 10 cubic meters. The slightly bell-shaped Command Module is a "lifting body;" its aerodynamic properties, similar to those of Apollo, are substantially better than those of Vostok, lessening reentry deceleration forces on its crew and enhancing landing zone targeting.

- *Orbital Work Module.*—Nearly spherical in shape, it allows cosmonauts to work, think, eat, relax, and sleep in surroundings that are spacious in comparison with those of the Command Module. The Orbital Work Module is also used as an airlock through which the crew may transfer to other spacecraft or embark on spacewalks; an airtight hatch is located at the interface that secures it to the Command Module.
- *Instrument and Systems Module.*—Contains a series of propulsion, maneuvering, and attitude control engines; associated fuel tanks; and a pressurized forward section holding major portions of the electronics for major operating systems (environmental, attitude control, communications, electrical, and propulsion). In some versions of Soyuz, solar cell arrays protrude, winglike, from opposite sides of this module, and provide charge and recharge of a set of internal chemical batteries. Use of solar panels ceased after Soyuz 11 but was resumed with the Soviet Union's component of the joint U.S.-Soviet Apollo-Soyuz Test Project, Soyuz ASTP,[3] and retained in the Soyuz T.

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[3] For a detailed account of this mission, see, Edward and Linda Ezell, *The Partnership—A History of the Apollo-Soyuz Test Project*, in the NASA History Series, NASA SP-4209, Washington, D.C., 1978.

Pre-Salyut Soyuz Space Flights

As the core vehicle for Soviet-manned space activities since 1967, the Soyuz has accomplished diversified objectives, many of them directly related to the growth of the Salyut space station program. Capable of flying with or without crews, Soyuz has served as a test bed to observe the physiological effects of long- and short-term spaceflight on human beings (as well as animals and plants), to evaluate rendezvous and docking techniques, and to appraise Earth remote-sensing equipment and new spacecraft systems.[*]

In early Soyuz flights, cosmonauts exercised skills later to be integrated into operations of the Salyut space stations. Specifically, the space complex resulting from the docking of Soyuz 4 and 5 in January 1969 was described by the Soviets as "the world's first space station"[4]—a somewhat puzzling description, as there was no connecting hatch. During the few hours when the two craft were linked in power, control, and communications, two cosmonauts from Soyuz 5 donned self-contained life-support systems, left their craft through a hatch in the Orbital Work Module and, using handrails, transferred into the docked Soyuz 4. This orbiting complex provided a total working volume of 632 cubic feet, the largest attained to that date.

Although most observers contend that a true space station should allow its occupants to move from one part of the facility to another without having to resort to spacewalking, the experience gained in the Soyuz 4 and 5 complex was valuable in the design and development of larger space station configurations.

In October 1969, the Soviets launched Soyuz 6, 7, and 8. In spite of their apparent failure to dock two of the vehicles, they succeeded in flying the three spacecraft with their seven cosmonauts in coordinated, close formation. At the time, the Soviets commented that the joint exercise evaluated autonomous navigation devices for use in close-formation flying and achieved a "rational distribution" of control between man and machine.

Acting on the assumption that the construction of future space stations would require a mastery of in-space welding techniques, the Soviets included a test unit on Soyuz 6. The device was operated remotely in vacuo and manually within the pressurized Orbital Workshop Module. Three welding techniques were tried in vacuo: 1) low-pressure compressed arc, 2) electron beam, and 3) arc with consumable electrode. Only the second was reported to be a complete success. More recently, the Soviets claimed those experiments can now be "seen as an impetus to the practical development of space technology."[5]

From its first use in April 1967 to the landing of Soyuz 9 in June 1970, and the initiation of space station operations, Soyuz spacecraft flew 15 persons on eight missions for a total of nearly 44 days of operations in space. At the close of this period, Soviet personnel—on Vostok, Voskhod, and Soyuz spacecraft—had accumulated a total of some 2,550 hours in space. By comparison, the total at this juncture for U.S. Mercury, Gemini, and Apollo spaceflight was far greater, being slightly over 6,260 personnel hours.

An apparent objective of the Soyuz program was to provide a multipurpose spacecraft to be used in connection with an orbital space station. Among its many roles, Soyuz was to be a temporary base for checking out the station, a supply and transport shuttle, and a vehicle for conducting additional independent studies. Given the growing proficiency the Soviets had shown with Soyuz, there remained no major technological barriers to their Salyut space station program.

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[*] Unfortunately, in demonstrating this latitude of functions, four cosmonauts lost their lives in two separate accidents, one in Soyuz 1 and three in Soyuz 11.

[4] This phrase was first used in a question by the Tass correspondent at the Cosmonauts' press conference in Moscow, Jan. 24, 1969. (Summary World Broadcasts, Su/2984/c/4). This same claim could have been made earlier, when two pairs of unmanned Soyuz prototypes previously achieved successful rendezvous and docking—except, of course, that some third vehicle would have been required to ferry a crew to staff them.

[5] V. Kubashov, *Pravda*, Moscow, Apr. 26, 1980, p. 3.

Salyut Space Station Characteristics

Because each new U.S. spacecraft system is designed "from scratch," American designers tend to emphasize quantum leaps in capability. By contrast, the Soviets reuse subsystems on different spacecraft whenever possible. For instance, the same propulsion, power, and thermal-control systems may be used on many vehicles. By relying on systems flight-proved in earlier space programs,* the Soviets may have been able to reduce costs and shorten the time spent in development and construction. Still, most of these elements require modification.[6]

The Soviets are believed to have begun work directly related to the development of Salyut space stations in the late 1960's. The first in this series of stations, Salyut 1, was launched in April 1971. To date, the Soviet Union has officially acknowledged that seven of these facilities have been launched, one of which (Salyut 2) broke up in orbit. Cosmos 557, which failed in orbit, is generally thought to have been a Salyut, although the Soviets have not confirmed this inference.[7] ** Only one other spacecraft, Cosmos 382, may have been a Salyut, but the evidence for this view is meager.[8] Though the Soviets experienced numerous failures early in the Salyut program, their strategy of using flight-proved subsystems in new programs to save time and costs was less at fault than was their weakness in the quality control of these subsystems.

Salyut-class space stations utilize several distinct major components:

- *Salyut.*—An orbital laboratory, 13 meters (m; one m = 3.3 ft.) in length, 4.2 m at maximum diameter and weighing approximately 19 tonnes; it provides over 100 m^3 of usable space for up to five crewmembers. The orbits of civil Salyuts (4, 6, and 7) lie between 362 and 338 kilometers (km; 1 km = 0.62 statute mile) above the Earth's surface; those of military Salyuts (3 and 5), between 274 and 241 km; that of Salyut 1, thought to be civil, between 277 and 251 km; all have an inclination of approximately 52 °. Two of the sections—a transfer/docking compartment and a working/living compartment—are habitable; the third is an unpressurized instrument/propulsion section. Solar arrays provide power. Salyuts 1 through 5 had one docking port; Salyuts 6 and 7, two ports. With a Soyuz transport craft docked at one end and a Progress resupply ship at the other, the total length of the complex is 29 m. Onboard laboratory equipment has included a multispectral camera, materials processing furnaces, and devices for scientific, medical, and technological tests.*
- *Soyuz.*—An early model of this class of transport that was retired from Salyut operations after Soyuz 40 in 1981. This spacecraft, flown with and without cosmonauts onboard, provided a transport link for two- or three-person crews and supplies between Earth and the Salyut vehicles, or, in the case of Soyuz 22, a solo flight.**
- *Soyuz T.*—Unveiled in December 1979. The successor to Soyuz,[9] and similar to it in external shape and dimensions, Soyuz T can

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*For example, the Soyuz and Salyut (1 and 4) propulsion systems were identical. Salyut 1 also used Soyuz solar panels. The propulsion unit of Molniya spacecraft was the same as that used on early lunar and interplanetary vehicles.

[6] K. P. Feoktistov and M. M. Markov, "Evolution of 'Salyut' Orbital Stations," *Zemlya i Vselennya,* September-October 1981, pp. 10-17.

[7] Nicholas L. Johnson, *Handbook of Soviet Manned Space Flight,* vol. 48, Science and Technology Series, American Astronautical Society, San Diego, Calif., 1980, p. 209. (Note that this book was published before the orbiting of Salyut 7.)

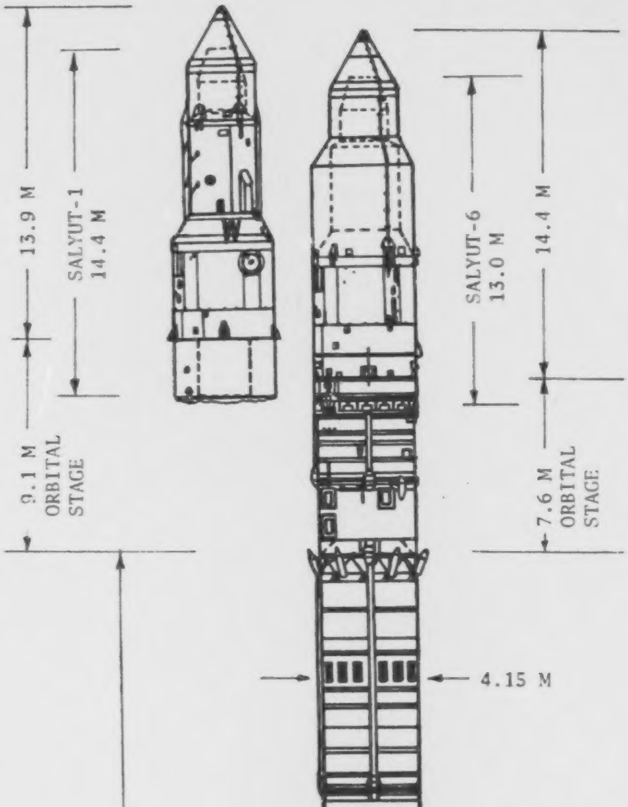
**As a rule, Soviet practice is to give a spacecraft a name appropriate to its class only if it achieves the purpose for which it was intended; craft which miscarry or are aborted receive either no name (as was the case for two that exploded in 1966) or the general appellation Cosmos. The failed Salyut 2 is the exception to this rule.

[8] Johnson, op. cit. Cosmos 382 was probably not a Salyut; it appears to have been considerably lighter and more maneuverable. Its altitude (5,000 km apogee), plane-change capability (51.6° to 55.9°), and perigee increase (from 320 km to 2,577 km) link it more probably to Cosmos 379.

*For a more detailed description of Salyut, see *Appendix A: The Soviet Salyut Space Program.*

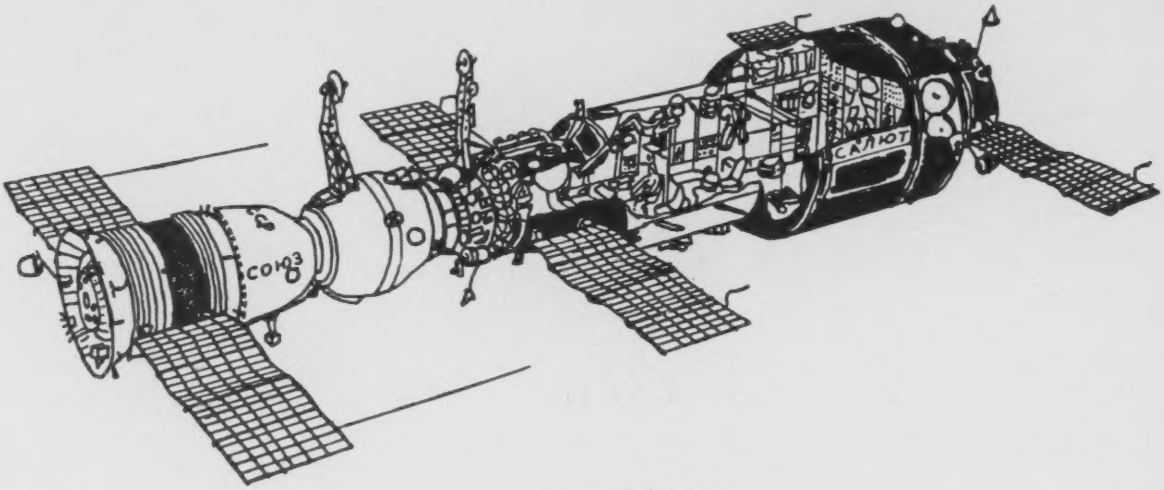
**Soyuz carried three cosmonauts on four flights. Soyuz 4 was launched with one cosmonaut, but returned carrying two cosmonauts from Soyuz 5; Soyuz 5 was launched with three and returned with one. After three crewmen on Soyuz 11 died from depressurization during reentry on June 6, 1971, cosmonauts were required to wear pressurized suits, and crew size was limited to two.

[9] Craig Covault, "Extensive Design Changes Mark Soyuz T," *Aviation Week & Space Technology* Jan. 14, 1980, p. 57.

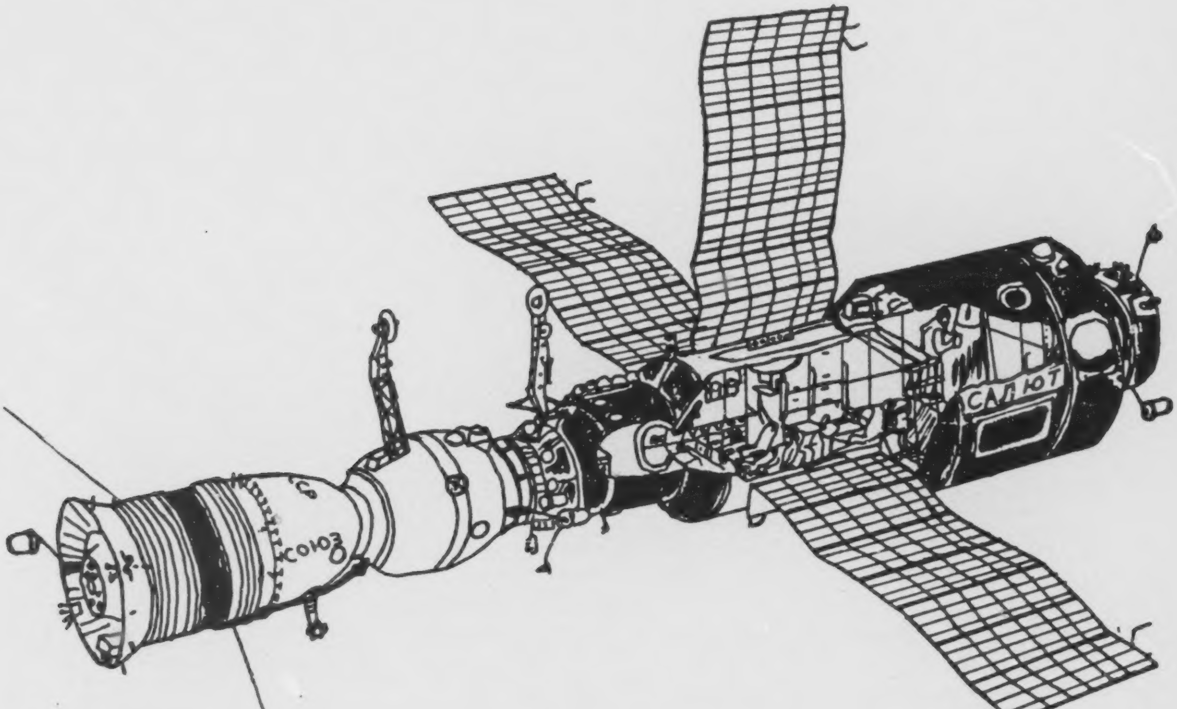

13.9 M
SALYUT-1
14.4 M
9.1 M
ORBITAL
STAGE
SALYUT-6
13.0 M
14.4 M
7.6 M
ORBITAL
STAGE
4.15 M
CORE STAGE — 35 M
STRAP ON STAGES (6)
20 M

Credit: ©C. P. Vick, 1982

Salyut launch vehicle: The Proton D-1 Launch Vehicle used to launch the Salyut Spacecraft Laboratory. It is a three-stage launch vehicle

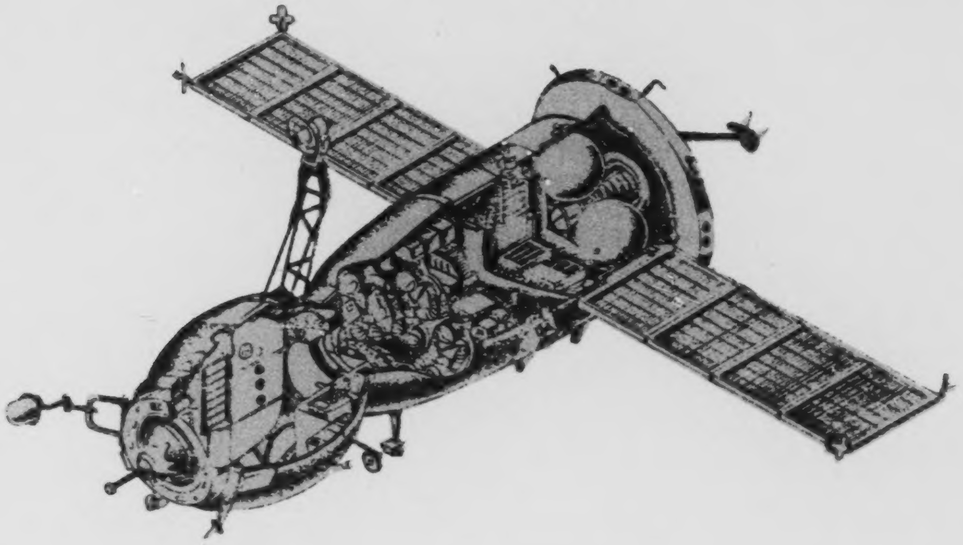


Soyuz 11 docked to Salyut 1



Soyuz 17/Salyut 4 represents a further development in the civilian Salyut Program. Major revisions are the absence of solar panels on the Soyuz ferry and the change to three large, steerable solar panels on the station

Soyuz T Spaceship



Principal Characteristics

Crew	2-3 persons
Weight	6,850kg
Weight of descent module	3,000kg
Length of the body	6.98m
Maximum diameter	2.72m
Span of extended solar battery panels	10.6m
Type of booster rocket	Soyuz

Credit: Drawing from "Mission Scientifique"
Franco-Sovietique
Saliout-7
France-USSR Scientific Mission
"Salyut-7 (Press Kit) for Soyuz T-6, 1982

transport as many as three people wearing pressure suits (or two people and a cargo pod) to the Salyuts.* Operating with solar panels, the craft sports advanced electronics and computers; it is more maneuverable than its predecessor, providing an automatic navigation control system that can be overridden for manual control, if desired. The orbital module of the vehicle, once its cargo has been unloaded into the station, can act as a container to hold used equipment and trash for subsequent destructive reentry.** The command module of Soyuz T is used to return the crew to Earth.

- *Progress.*—An unmanned transport of slightly over 7 tonnes, based on Soyuz design and using internal batteries rather than power derived from solar cells, it links to Salyut automatically, delivering equipment, parts, fuel, and other consumables.[10] The cargo capacity of Progress is about 2.3 tonnes of food, water, mail, film, equipment, and propellants. Oxygen regenerators for Salyut's life-support system are resupplied, along with gaseous nitrogen, if needed.[11] Salyut cosmonauts transfer much of this cargo into the station manually, but propellant for the station is pumped automatically. Using residual propellant, Progress spacecraft also double as space tugs, capable of pushing Salyuts into higher orbit. The last service which Progress can render to Salyut is to accept its refuse. Because it is not designed for recovery, Progress is jettisoned and destroyed upon reentry into the atmosphere.
- *Cosmos 929-Class Module.*[12]—Designed to double the habitable volume of Salyut, this module is flown without crew to the station and docked automatically. Carrying its own propulsion, guidance, and life-support systems, it is designed with several docking ports and an ejectable "sub-module" which is large enough to return the station's crew and/or heavy equipment to Earth. The first such module, Cosmos 929, was orbited July 17, 1977, and tested as a freeflyer. The next in the series, designated Cosmos 1267, docked with Salyut 6 in 1981, forming an orbital complex that flew, uninhabited, for 13 months while a variety of automated system checkouts and flight-stability experiments were carried out. The latest module of this type, Cosmos 1443 (which may weigh as much as 20 tonnes), docked with Salyut 7 in March 1983.[13] *

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*Soyuz T-3, T-6, T-7, and T-8 had crews of three.

**The orbital module has not been left attached to Salyut. Without propulsion and flight control, its disposal would be difficult.

[10] K. P. Feoktistov, *Scientific Orbital Complex*. Monograph reproduced in English in Joint Publications Research Service (JPRS), *USSR Report: Space*, June 17, 1980.

[11] *Tass* in English, 0753 GMT, Jan. 24, 1978.

[12] "Soviets Show Assembly of Space Station Units," *AW&ST*, June 29, 1981, p. 21.

[13] "Soviets Launch Module to Enlarge Salyut 7," *AW&ST*, Mar. 7, 1983, p. 19.

*The long hiatus between the flights of Cosmos 1267 and 1443 can be attributed to the fact that the Cosmos 1267 test program was not terminated until the summer of 1982, at which point the Soyuz T-5 mission was already in progress.

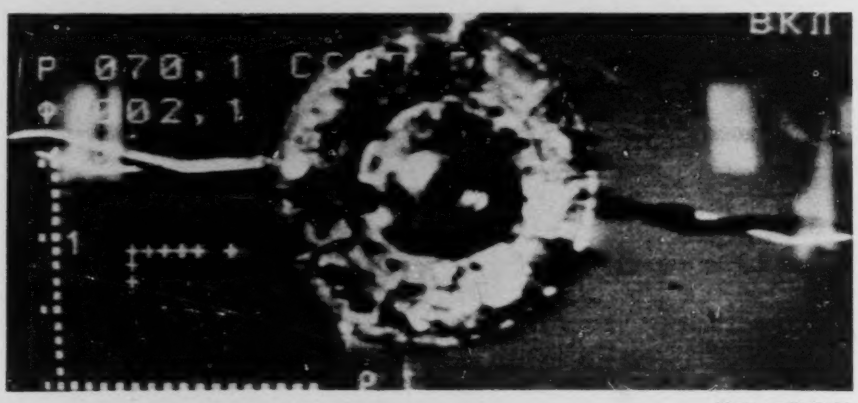
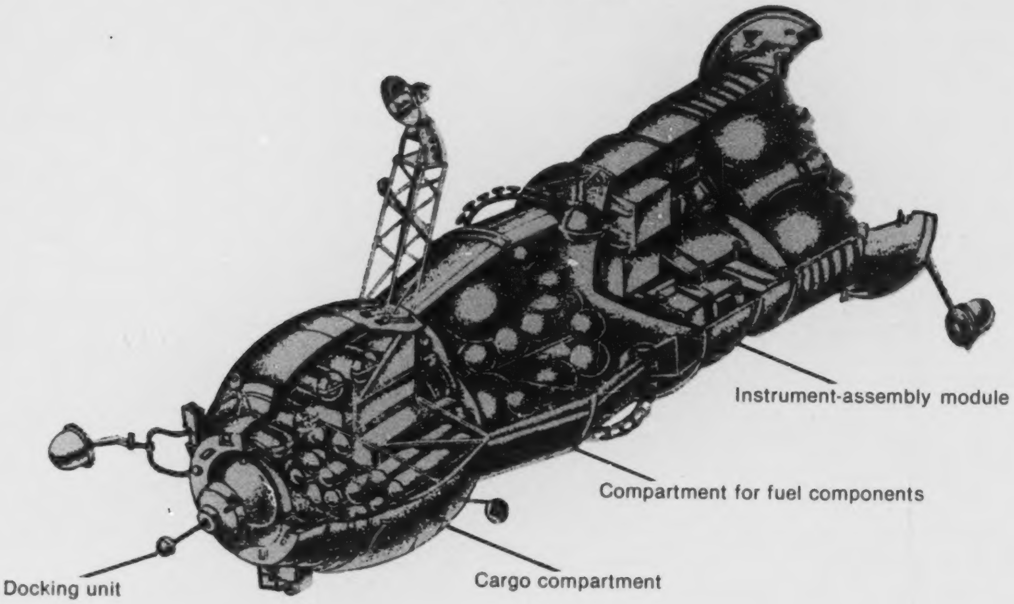


Photo credit: TASS

Link-up in Orbit: On June 28, 1983, the spaceship Soyuz T-9 linked up with the orbital complex Salyut T-7—"Cosmos-1443"

Progress Cargo Spaceship


Instrument-assembly module
Compartment for fuel components
Docking unit
Cargo compartment

Principal Characteristics

Weight	7,020kg
Weight of cargo delivered to the station	about 2,300kg
including:	
-in the cargo compartment	up to 1,300kg
-in the compartment for fuel components	up to 1,000kg
Maximum length	7.94m
Maximum diameter of pressurized compartments	2.2m
Type of booster rocket	Soyuz
Duration of flight:	
independent	up to 3 days
when docked with the orbital station	up to 30 days
Orbit parameters:	
height	200 to 350 km
inclination	51.6 degrees
rotation period	about 89 minutes

Credit: Drawing from "Mission Scientifique"
Franco-Sovietique
Saliout-7
France-USSR Scientific Mission
"Salyut-7 (Press Kit) for Soyuz T-6, 1982

Salyut Activities

Launch dates of Salyut space stations announced by the Soviets:[14]

Salyut 1	Apr. 19, 1971
Salyut 2	Apr. 3, 1973 (failed)
Salyut 3	June 25, 1974
Salyut 4	Dec. 26, 1974
Salyut 5	June 22, 1976
Salyut 6	Sept. 29, 1977
Salyut 7	Apr. 19, 1982

Salyut 1

The first in the Salyut series carried an Orion 1 telescope for obtaining spectrograms of stars in the 2,000 to 3,000 angstrom region of the electromagnetic spectrum; a gamma-ray telescope, called Anna III, provided observations unattainable from Earth. Several optical and multispectral cameras were used for astronomical and Earth photography. Photo sessions of geological and meteorological phenomena were coordinated with aircraft flights and orbiting weather satellites. Making use of a hydroponic farm, biological experiments centered on the effects of weightlessness on plant growth and nutrition. Long-term implications of the effects of microgravity on the human organism were also studied.

A first attempt to board the station by a three-man crew on Soyuz 10 was thwarted by faulty docking equipment on the Soyuz. A second attempt by Soyuz 11 cosmonauts was successful; this three-man crew became the world's first occupants of what some would describe as a true "space station"—i.e., long-term in-space infrastructure that accommodates human beings—residing in Salyut for 23 days. This initial success, however, was followed by an unhappy ending. A valve, intended for equalizing internal and external pressures as the spacecraft descended through the atmosphere during recovery, jerked open at the instant of the explosive separation of the command and orbital modules, permitting the cabin's atmosphere to escape. The cosmonauts, wearing no spacesuits, perished.* From then until the launch of Soyuz T-3 in 1980, Soyuz vehicles were redesigned to allow the crew to wear spacesuits. Crew size was reduced to two to provide sufficient room for the suits and related equipment. Salyut 1 was intentionally removed from orbit 175 days after launch.

Salyut 2

This vehicle did not achieve stability in orbit, began to tumble, and broke up before crews could occupy it.

Salyut 3

Unlike Salyut 1, which had two sets of fixed solar panels fore and aft, Salyut 3 carried two larger panels attached just aft of the centerbody, on the rear transfer module.[15] These panels could be rotated so the craft could continue to receive solar power whenever it was in sunlight, whatever its orientation. Salyut 3 was also modified so that its docking port was aft.[16] Other noteworthy modifications included higher efficiency power and life-support systems and more convenient interior design.

Cosmonauts aboard Salyut 3 conducted some 400 scientific and technical experiments, including high-resolution photo reconnaissance and/or Earth resources observation, spectrographic study of aerosol particles in the Earth's atmosphere, the culturing of bacteria, and the recycling of water.

The crew of Soyuz 14 resided aboard Salyut 3 for 14 days, but a follow-on Soyuz 15 crew proved unable to effect docking. Overall, the station remained operational for twice its design lifetime. Some 2 months after Salyut 3's final crew departed, a data capsule was ejected and recovered on Earth. That only a few photographs,

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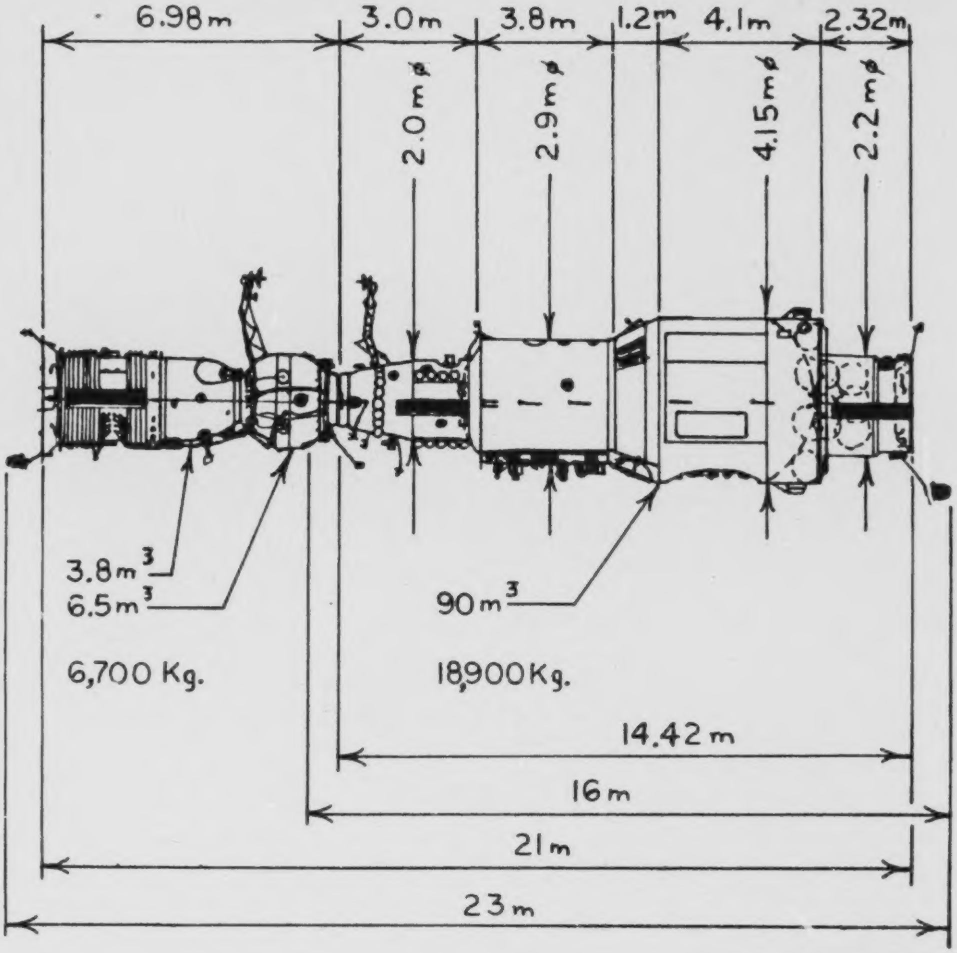
[14] Cosmos 557, launched May 11, 1973, has been identified in Western circles as a successfully orbited Salyut, although the station suffered a propulsion or command-sequencer failure, rendering it useless for human occupation. The vehicle rapidly decayed in orbital altitude, reentering the atmosphere on May 22, 1973. See, "Reception of Radio Signals From Cosmos 557," The Kettering Group, *Spaceflight*, vol. 16, 1974, pp. 39-40.

*The cause of death was embolism, i.e., the formation of bubbles in the bloodstream.

[15] Although all subsequent Salyuts retained this midship mounting of solar panels, they were placed farther aft on Salyuts 3 and 5 than on Salyuts 4, 6, and 7. See, for example, *AW&ST*, Dec. 4, 1978, p. 17.

[16] Ibid.



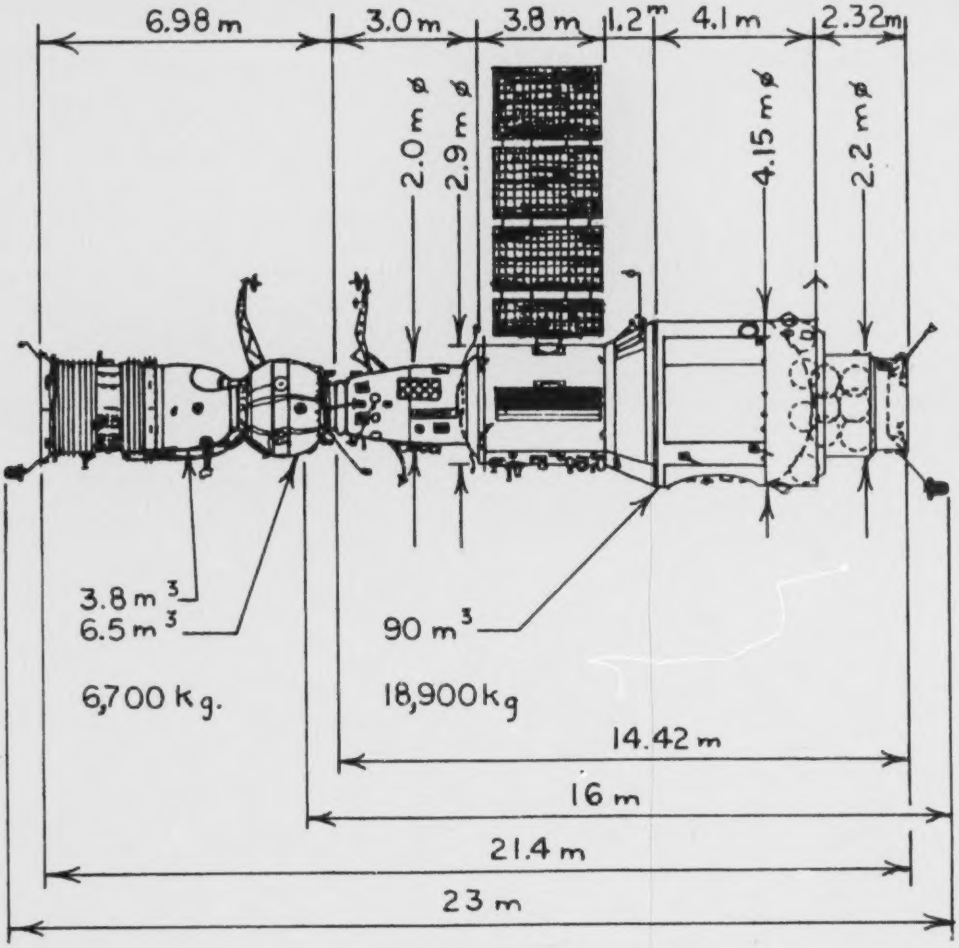
Credit: ©C. P. Vick, 1983

Soyuz 11/Salyut 1. Total volume: 100.3 m^3. Total weight: 25,600 kg. Total solar panel surface area: 42m^2

showing noncritical interior equipment aboard Salyut 3, have been released encourages speculation that its primary mission was probably military.

Salyut 4

The design of this station, seemingly primarily civilian in character, allowed the crew more ready access for repair and replacement purposes. Two navigation systems for the station's automatic control were evaluated, as was a new teletype system. Onboard scientific equipment, weighing about 2.5 tonnes, was of much greater variety and capability than that carried on previous stations. The cosmonauts' time was devoted each day to a specific area of investigation—astronomical, Earth resources, or biomedical. X-ray, solar, and infrared spectrometric telescopes were among the host of instruments employed. Making repeated observations of agricultural patterns, forests, and maritime areas, the crew collected a large body of data on Earth resources. They also studied micro-organisms, higher plants, and the human cardiovascular system, measuring the tone of blood vessels and the circulation of blood to the



Credit: ©C. P. Vick, 1983

Soyuz 18/Salyut 4: Total volume: 100.3 m^3. Total weight: 25,600 kg. Total solar panel surface area: 60 m^2. Solar panel span: 17 m

brain. The cosmonauts also evaluated the effectiveness of various exercise and diet regimes for counteracting the deconditioning effects of microgravity.

The first crew to board Salyut 4 arrived on Soyuz 17; they remained for 29 days. The mission of their scheduled successors, the crew of Soyuz 18A,[17] was aborted during ascent. Next aboard were the Soyuz 18B team; they remained on the station for 62 days. Soyuz 20, a vehicle without crew, carried biological specimens; it docked and remained at the station for 89 days before returning to Earth. Part of its mission was to determine whether Soyuz could remain without power for a relatively long time before restarting its power supply without mishap—an important consideration in planning for one crew to remain aboard a Salyut for a lengthy mission. Salyut 4 was purposely taken out of orbit after 770 days of flight.

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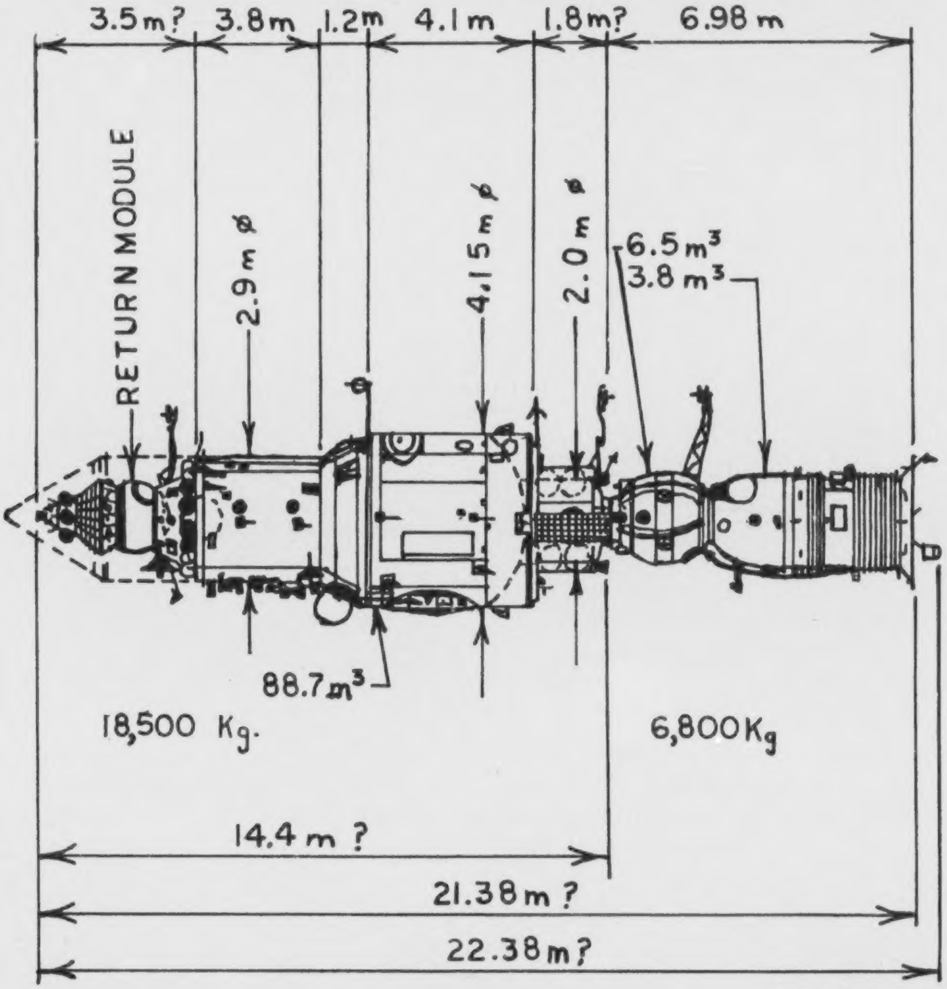
[17] 18A is the U.S. designation. The Soviets refer to this event as the April 5 anomaly.

Salyut 5

Salyut 5, the second station thought by Western analysts to be primarily military, was the last in the Salyut series to carry only one docking port, a design characteristic which effectively prevents a resupply vehicle from docking when a crew of cosmonauts is already aboard.* Salyut 5 demonstrated a high-resolution camera, similar to that on Salyut 3, that was used to study mineral deposits, seismic areas, environmental damage caused by mud streams and railway construction paths. A device for smelting certain metals—bismuth, tin, lead, and cadmium—and a crystal growth experiment were evaluated in the station's microgravity environment. As in previous Salyuts, biological experiments on fish, plants, and fruit flies were also conducted; algae and higher order plants were cultivated to examine the effects of the spaceflight environment on their development and growth.



Credit: ©C. P. Vick, 1983

"Military" Salyut Conceptional Design: Total volume: 99 m^3. Total mass: 25,300 kg. Total solar panel surface area (estimated): over 50 m^2. Total mass: over 25,000 to 25,300 kg. Only a few written descriptions, a few movie film segments, and a few photographs of the internal and external design layout of the Military Salyut 3 and 5 vehicles have been released

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*It is technically possible, but too risky, to back off one spacecraft and then dock another while the crew is on board the station.

Over the course of Salyut 5's stay in orbit, Soyuz 21 brought a two-man crew, who remained on the station for 49 days; the crew of Soyuz 23 failed to dock; and the crew of Soyuz 24 remained aboard for 16 days.

Like Salyut 3, this station ejected a recoverable pod to Earth after its last crew departed, and, as with Salyut 3, the Soviets have released only internal photographs of limited interest. The station remained in orbit for 412 days before it was commanded to reenter.

Salyut 6

By far the most productive of Soviet space stations, this "second generation" Salyut included two docking ports, fore and aft; the station was fashioned to support a new propulsion system capable of being refueled in orbit. A water-regeneration device became a standard feature of the life-support system, supplying crewmembers with wash water; fresh drinking water was stored. Many of the experimental systems tested on earlier stations became operational on Salyut 6. A new multispectral camera (which had been flight-tested on Soyuz 22) and astronomical telescopes were flown. During its mission, cosmonauts assembled and deployed from Salyut's aft end a dish antenna used in mapping radio emissions from the Sun and the Milky Way, although the ultimate success of this experiment is in doubt.[18] Several materials processing furnaces were appraised, and infrared-sensitive semiconductors were produced. Other experiments produced superconductors, eutectics, alloys, pure metals, glass, ionic crystals, and metal oxides.[19] Salyut 6 cosmonauts also tested newly designed extravehicular spacesuits.

Cosmonauts routinely worked as in-orbit repairmen, enabling the station's design life of 18 months to be greatly surpassed. Because of the longevity of Salyut 6, perhaps to the surprise even of the Soviets themselves, its crews registered an impressive list of accomplishments. Space applications and Earth observations each accounted for about one-third of the cosmonauts' work schedule; the final third was split between biomedical studies and astrophysics.

The two docking ports permitted 33 successful dockings using vehicles with and without cosmonauts. At least two crews tried but failed to dock with the station. Five long-duration cosmonaut crews and 11 visiting crews accumulated a total of 676 days of operation. New duration records for human spaceflight were successively established: 96, 140, 175, and 185 days. During Salyut 6's lifetime, eight cosmonauts from the Soviet bloc resided in Salyut for short periods; Soyuz 33, carrying a non-Soviet crewmember, along with a Soviet pilot, failed to dock.* Salyut 6 operations introduced the use of Soyuz T and Progress vehicles, multiple-crew dockings, refueling in orbit, and the Cosmos 1267 module.**

Cosmos 1267 docked with Salyut 6 in June 1981 for a long series of what were described as checkouts of automated systems and "dynamic tests" of the overall response of the structure to maneuvers while docked with another vehicle. According to Soviet space planners, Cosmos 1267 represented a "prototype space module," built to expand the operations of future stations; such modules could be dedicated to materials processing and astronomical or other scientific pursuits, or they could be outfitted as living quarters. They could also be undocked from Salyut, flown alongside the station and reconnected. This configuration would be particularly useful for the conduct of experiments in materials processing, because it could avoid perturbations caused by the station's reactions to movements of the cosmonauts.[20]

The Soviets apparently were undecided about using their long-lived Salyut 6 for future missions,

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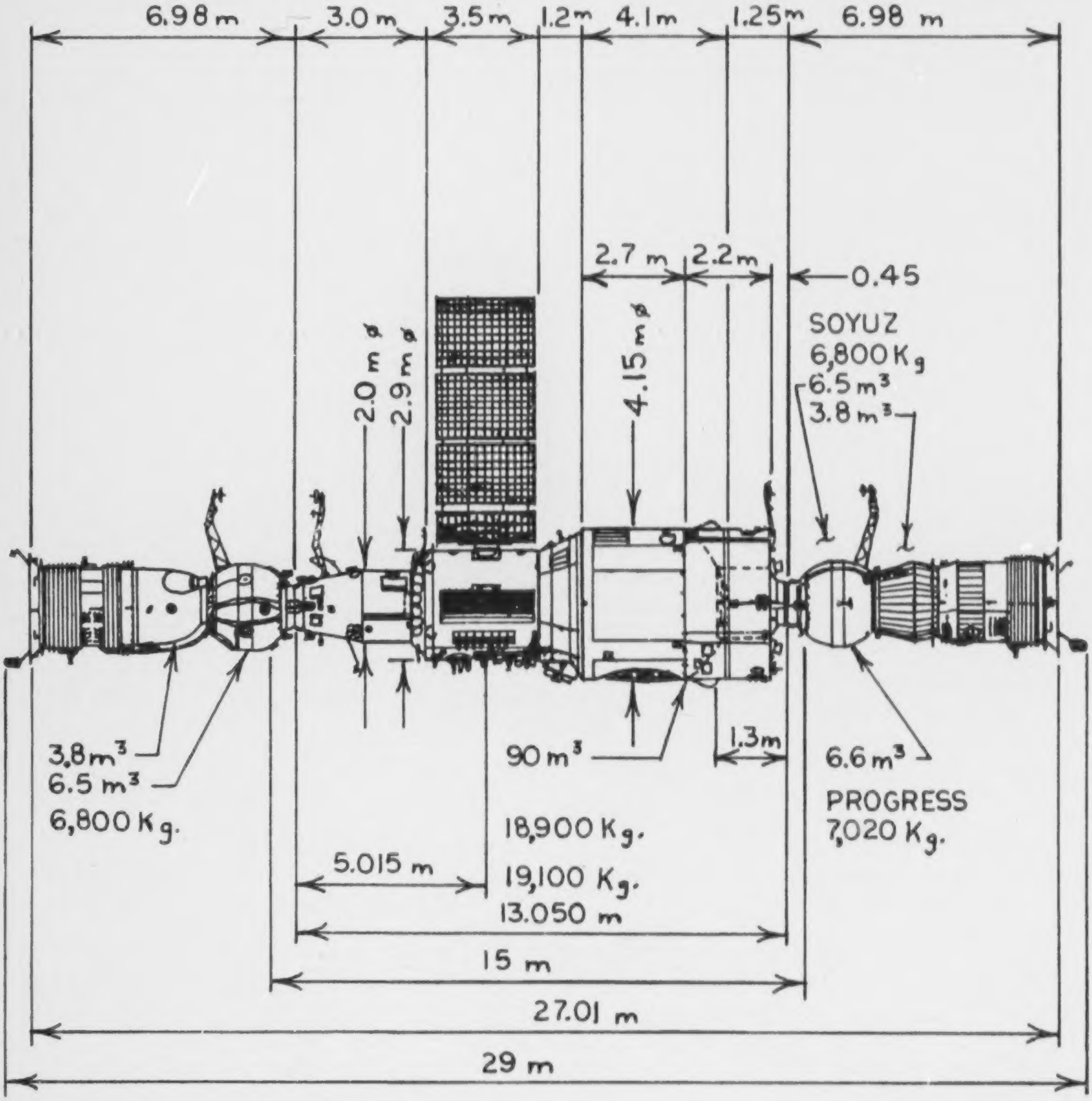
[18] Craig Covault, "Radio Telescope Erected on Salyut 6," *AW&ST*, Aug. 13, 1979, pp. 54-55. See also "Soviets Ready Salyut 6 Crew Return," *AW&ST*, Aug. 13, 1979, p. 21.

[19] James C. Brown, *Materials Processing on the Soviet Salyut 6 Space Station*, Memorandum SWM81-10041, Central Intelligence Agency, National Foreign Assessment Center, Apr. 1, 1981. Soviet research in the materials processing-in-space arena appears extensive. According to MIT professor Harry Gatos, before a House space subcommittee review of space processing, a large new Soviet research institute employs several hundred full-time scientists working on space materials processing. Other countries involved in this institute include Poland, Hungary, Czechoslovakia, and France. See *Astronautics and Aeronautics*, September 1979, p. 9.

*Soyuz 25 with two Soviet crew also failed to dock with Salyut 6.

**There was no crew aboard either Cosmos 1267 and Salyut 6 during their docking of 40 days, after which both were deorbited.

[20] *From Sputnik to Salyut: 25 Years of the Space Age*, Novosti Press Agency Publishing House, 1982, passim.


6.98 m
3.0 m
3.5 m
1.2 m
4.1 m
1.25 m
6.98 m
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SOYUZ
6,800 Kg
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3.8 m³
2.0 m ø
2.9 m ø
4.15 m ø
3,8 m³
6.5 m³
6,800 Kg.
90 m³
1.3 m
6.6 m³
PROGRESS
7,020 Kg.
18,900 Kg.
5.015 m
19,100 Kg.
13.050 m
15 m
27.01 m
29 m

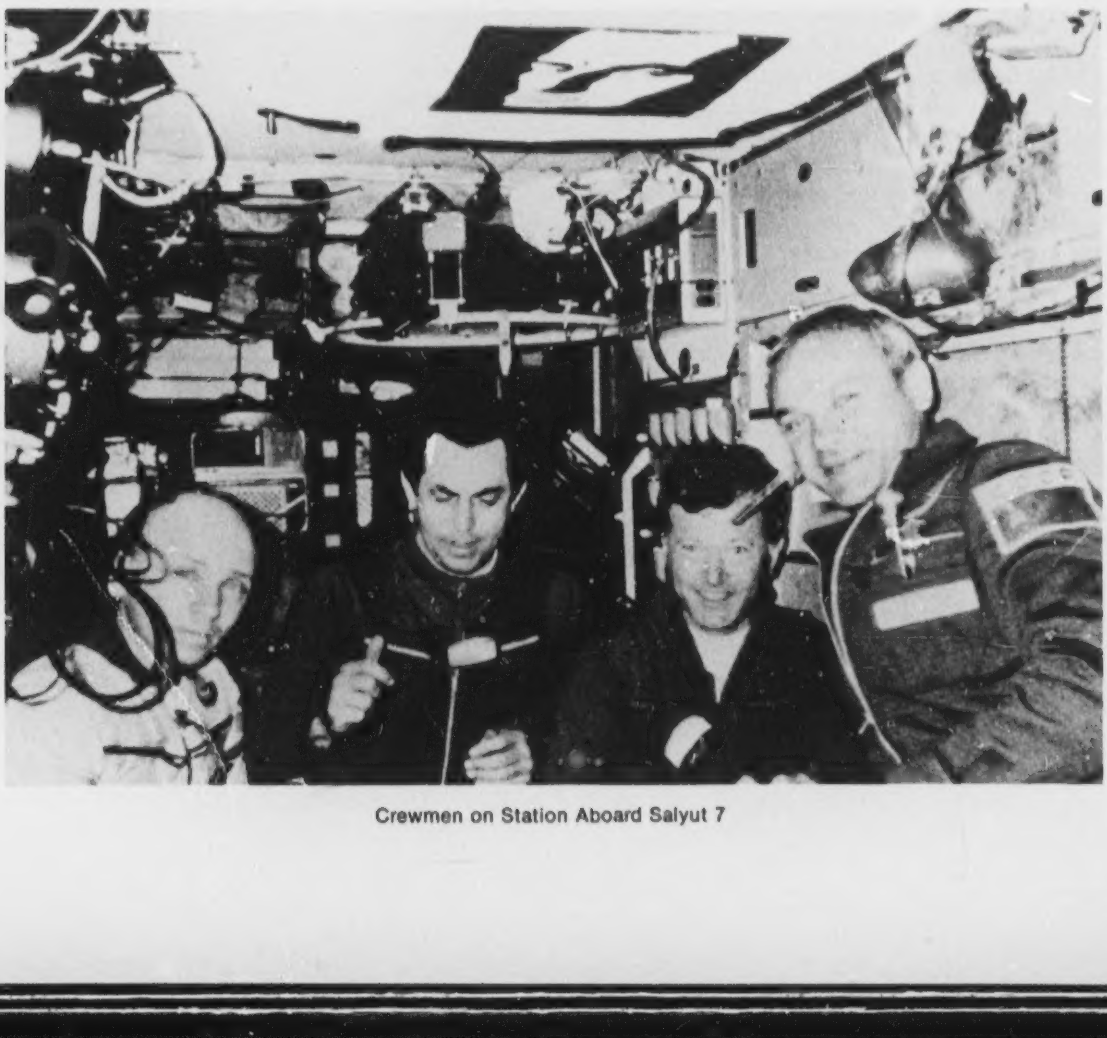
Credit: ©C. P. Vick, 1983

Salyut 6 and attached transport vehicles Soyuz and Progress in various combinations; diagram shows, left to right, Soyuz, Salyut and Progress: Total mass with two Soyuz: 32,500 to 32,600 kg. Total mass with one Soyuz and one Progress: 32,720 to 32,770 kg. Total mass with one Soyuz: 25,700 to 25,750 kg. Total volume with two Soyuz: 110.6 m³. Total volume with one Soyuz and one Progress: 106.9 m³. Total volume with one Soyuz: 100.3 m³. Total solar panel surface area: 60 m². Solar panel span: 17 m and twice had Cosmos 1267 boost the complex into a higher orbit. After Salyut 7 was launched, Cosmos 1267 propelled Salyut 6 into a destructive reentry on July 29, 1982. The stay of Salyut 6 in orbit lasted 4 years and 10 months.[21] [22]

Salyut 7

Currently, the Soviet Union is maintaining Salyut 7 in orbit. Soviet space officials indicate it is similar in size and shape to its predecessor.[23] [24] Two docking ports are again provided, one of which has been modified to handle larger spacecraft. The standard station control system on Salyut 7—the result of experiments conducted on other stations—allows its crews to operate the facility in more automatic modes.[25] Recommendations from cosmonauts who had lived aboard Salyut 6 led to an interior "modernization program" to make Salyut 7 more livable. Designers have taken special care to protect certain observation windows, shielding both inside and outside panels with removable covers, because contaminants from propulsion unit firings, as well as impacts from micrometeorites, degraded the windows on Salyut 6. The color scheme was changed to improve the residential and working environment, and a refrigerator was installed.

Salyut 6 carried a submillimeter wavelength infrared telescope; Salyut 7 contains a complex of X-ray equipment. The first long-duration crew



Crewmen on Station Aboard Salyut 7

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[21] Peter Smolders, "Saluting Salyut's Space Record," *New Scientist*, Oct. 11, 1979, pp. 118-121.

[22] "TASS Reports Termination of Flight of Salyut 6 Station," *Pravda*, July 30, 1982, p. 1.

[23] B. Konovalov, "A Trip Through the 'Salyut 7,' " *Izvestiya*, May 18, 1982, p. 3.

[24] "The New 'Salyut 7' is a Modernized Station," *Air and Cosmos*, No. 910, June 5, 1982, p. 43.

[25] "Salyut 7 Incorporates State-of-Art Upgrades," *AW&ST*, July 26, 1982, pp. 26-27.

used a new computer-controlled 300-lb materials-processing furnace to produce several pounds of semiconductor monocrystals. This furnace operates automatically when the station is unoccupied. New systems for medical examination and diagnosis have improved the range of biomedical parameters that can be monitored, either onboard by the cosmonauts or remotely from the ground. For example, a thorough electrocardiogram can be obtained automatically. Measurements of blood circulation in the cerebral cortex, an important parameter in near-weightless conditions, are receiving particular attention.

Performing about 300 experiments, the station's first long-term crew worked to meet orders from 500 national economic and scientific centers. Soviet officials stated that, for the first time, a Salyut space station undertook "direct research production tasks."[26] Some 20,000 photographs of the Earth's surface were reportedly taken during the first phase of this operation.

Initial operations of Salyut 7 relied on Progress vehicles for resupply and refueling.[27] The Soyuz T-5 transported a crew of two to the Salyut in May 1982. Subsequently, a Soyuz T-6 with three aboard, including a French spationaut, and a Soyuz T-7 with three, including the world's second woman cosmonaut, visited the primary crew on separate occasions. The primary crew set a new world endurance record for spaceflight: 211 days.

On March 2, 1983, "a modular transport ship," Cosmos 1443 (a Cosmos 929-class module), was launched, and docked with Salyut 7 on March 10 in a configuration similar to the Salyut-6/Cosmos-1267 complex.[28] Although a Soyuz craft with a crew of three aboard failed to dock with the complex in April 1983,[29] a two-person crew boarded the station on June 28, 1983, and remain aboard as of this writing.

Photo credit: Novosti

Members of the Soyuz-9 space mission

The Salyut-7/Cosmos-1443 orbital complex was thought capable of housing as many as six crewmembers.* Stationing of that many people aboard the complex would have born out earlier Soviet pronouncements that this configuration was a prototype for future larger scale space stations. On August 14, 1983, Cosmos 1443, along with its descent module (with a capacity for returning one-half tonne of cargo, but not a crew member) was undocked from Salyut 7.** Then on September 19, 1983, Cosmos 1443 was inten-

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[26] "Kuznetsov Presents Awards to Salyut 7 Cosmonauts," Moscow Domestic Service, LD291458, Dec. 29, 1982.

[27] In the early phase of Salyut 7, two small "subsatellites" were launched from the station by its first long-duration crew. These satellites, Iskra 2 and Iskra 3, were constructed by students of a Moscow Aviation Institute and served as communications satellites for amateur radio enthusiasts. The two satellites were "launched" from the station's airlock. For a detailed account of early work on Salyut 7, see: "Salyut Mission Report," by Neville Kidger, *Spaceflight*, January 1983, pp. 28-29.

[28] "Soviets Launch Module to Enlarge Salyut 7," *AW&ST*, Mar. 7, 1983, p. 19.

[29] "Soviet Docking in Space Fails; Mission Aborted," *Washington Post*, Apr. 24, 1983, pp. A-1, A-12.

*It is not clear that docking arrangements allow more than one Soyuz T to dock with a Salyut 7/Cosmos 1443-type combination at a time; such a provision would be expected in the future.

**A rather complex sequence of events occurred during August 1983. Cosmos 1443 undocked on August 14. Then on August 16, Soyuz T-9 undocked, the Salyut was rotated through 180°, and the

The crew of the Soyuz T-7 spaceship (from left to right)—crew commander Leonid Popov, Pilot-Cosmonaut of the U.S.S.R.; researcher engineer Svetlana Savitskaya; and flight engineer Novosti

tionally deorbited, perhaps because of a serious malfunction affecting its operation.[30] More recently, Salyut 7 itself has experienced a serious propellant leak, leaving it with two of its three oxidizer tanks empty and 16 of its 32 attitude control thrusters unusable. Because of the difficulty of making repairs, it is less likely that Salyut 7 will become a major component of a large modular station.

Military Utility of Salyut

Salyut space stations serve both military and civilian needs.[31] Through the mid-1970's, each station could be distinguished as military or civilian by its design, communications frequencies, orbits, onboard equipment, and crew composition. Such distinctions are virtually impossible to draw for the Salyut 6 and 7 stations. Indeed, now that 6 years have passed since the last Salyut clearly identifiable as military was used, a separate military Salyut program may no longer exist.

Civilian Salyuts (1 and 4) were flown in higher orbits, increasing their value for astronomical observations. Telemetry was typical of Soviet nonmilitary spacecraft, and the crew commander, although usually from the Soviet military, was accompanied by a civilian flight engineer.

In contrast, military Salyuts (3 and 5) were flown in lower orbits, presumably to get the most out of the capabilities of onboard photo reconnaissance assets and activities which replaced the astronomical activities of civilian flights.* Flights of these Salyuts, typically using radio frequencies

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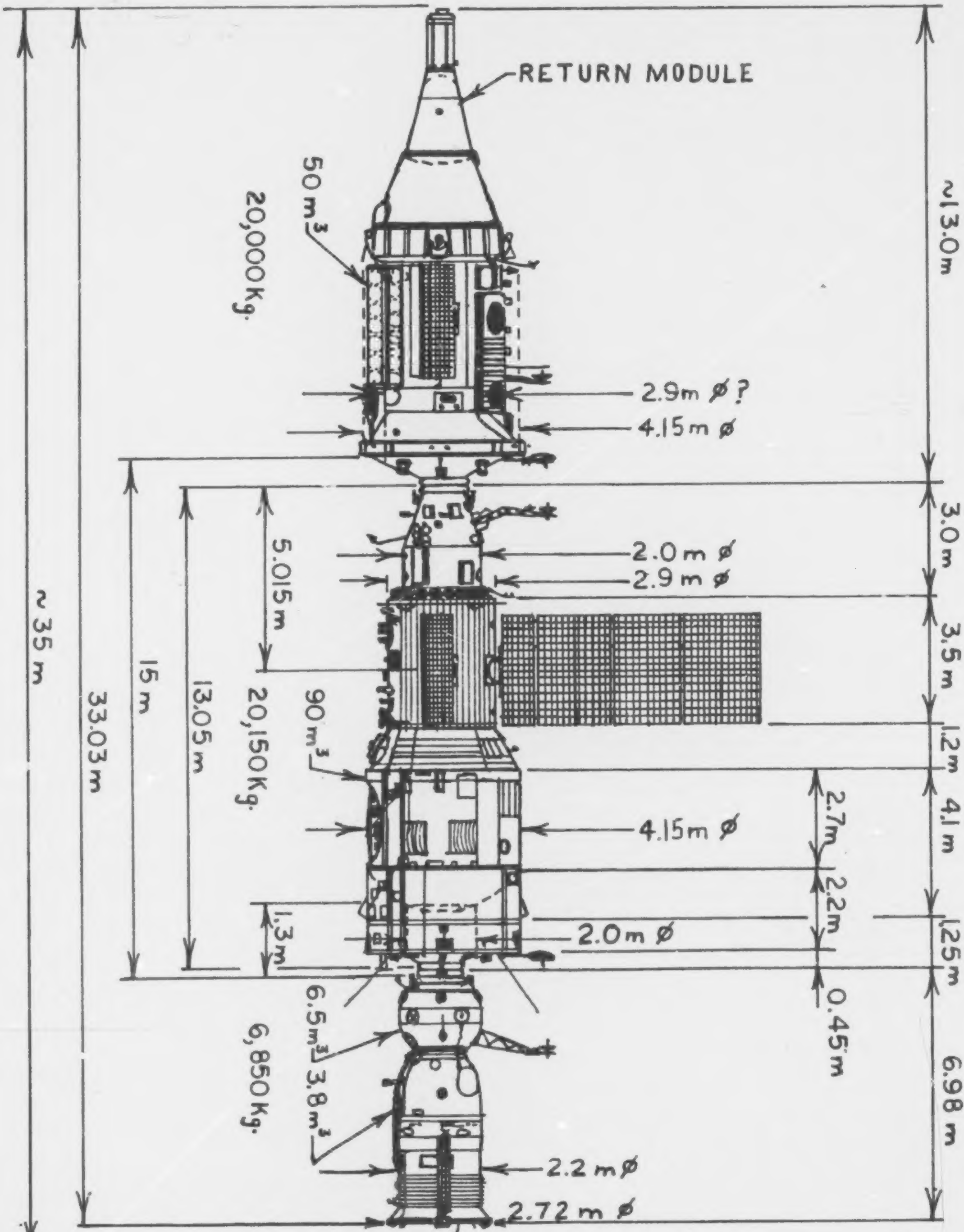
Soyuz was redocked at the "front" end of the station. On August 17, Progress 17, bringing additional fuel, air, and water was docked to the "back" end of the station. On August 19, the descent module from Cosmos 1443 landed in Kazakhstan, U.S.S.R. Since the undocking of Cosmos 1443 and Salyut 7, the two spacecraft went out of and (through firing of the motor of the Progress attached to Salyut) came back into orbital phase, but apparently no attempt was made to redock prior to the intentional deorbiting of Cosmos 1443.

[30] *Aviation Week & Space Technology*, Oct. 10, 1983, p. 25.

[31] Johnson, op. cit., pp. 213-217.

*In order to maintain such a low orbit for very long, large quantities of propellant must be expended.


RETURN MODULE
50 m³
20,000 Kg.
~13.0 m
2.9m ø ?
4.15m ø
5.015 m
2.0 m ø
2.9 m ø
3.0 m
3.5 m
90 m³
20,150 Kg.
1.2 m
4.15m ø
2.7m
4.1 m
2.2m
2.0m ø
1.3m
1.25m
0.45m
6.5m³
3.8m³
6,850 Kg.
6.98 m
2.2 mø
2.72 m ø
~35 m
33.03m
15 m
13.05m

Credit: ©C. P. Vick, 1983

Cosmos 1443/Salyut 7/Soyuz T: Total mass: about 47,000 kg. Total solar panel surface area: 100 m². Total power output: 7 kW. Total volume: 150.3 m³. Solar panel span: 16-17 m

associated with other Soviet military space missions, were conducted by all-military crews. They remained in orbit for shorter periods than their civilian counterparts and ejected capsules for recovery on Earth.

Of course, there must be some military interest in scientific programs. For instance, astronomical investigations completed by Salyut crews maintained the orientation of certain equipment to an accuracy of a few arc-seconds, a capability related to what might be needed to aim directed-energy weaponry. The materials processed in microgravity could range from electronic components to new pharmaceuticals.

Many activities aboard Salyut might be described, in the United States, as civil, but others might well have military implications. Whether military activities aboard these stations pose a serious, near-term threat to the United States cannot be determined from the open literature. Certain military operations may have been turned over to automated spacecraft: Soviet advancements in satellite photo reconnaissance may have reduced the need for crewmembers to gather these data.

Comparisons with the U.S. program are also complicated by the fact that no operational requirements for U.S. military missions aboard a space station, particularly those requiring crewmembers, have been formally stated.[32] However, in view of President Reagan's speech in March, 1983, on the subject of defense against ballistic missiles, this assessment may be changing.[33] In any case, the military value of the Soviet space station remains open to question.

Capability Base for Salyut Program

The Soviet technology base must inevitably affect its space program. A thorough appraisal of this base cannot be obtained because the Soviets tightly control what information about the program is made public. Observers, however, have noted these characteristics:[34]

- *Simplicity.*—Compared with similar Western systems, Soviet components are, in general, relatively less complicated.
- *Commonality.*—Once a basic system or subsystem is developed, it is used as much as possible thereafter. With this approach, a relatively narrow technological base can serve much broader needs.
- *Gradual Change.*—This principle derives from the other two. Because each system is closely related to its predecessor, the risks attendant on innovation are reduced.

In sum, the Soviets prefer to use a single, reliable basic design over a relatively long time in order to provide several generations of systems for similar or related uses.

Professional surveys of industrial technology in the U.S.S.R. suggest that the Soviets are generally unwilling or unable to undertake rapid innovation. In some cases, however, a few critical suppliers and supporting industries have been able to set priorities that led to rapid change.

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[32] At the Space Station Symposium held in Washington, D.C., in July 1983, Richard DeLauer, Undersecretary of Defense for Research and Engineering, reiterated this position. For an earlier discussion, see: Joel Levy, et al., "Potential Military Applications of Space Platforms and Space Stations," *Eascon 82, 15th Annual Electronics and Aerospace Systems Conference, IEEE Conference Record 82CH1828-3,* Sept. 20-22, 1982, pp. 269-276. This paper states: "It is apparent that, at this time, the DOD has not defined any firm requirements for space platforms or space stations." The military utility of a manned space station, say for photo reconnaissance, requires detailed tradeoff studies, " . . . in order to evaluate whether the increase in system performance due to man's presence warrants the increase of approximately an order of magnitude in the cost of the program. Any increase in system performance achieved by such means would be measured by some, as yet undefined, weighing of factors such as cost, risk, survivability, reliability, threat recognition and the time to respond."

[33] "President Seeks Futuristic Defense Against Missiles," *Washington Post,* Mar. 24, 1983, pp. A-1, A-13. See also, "Reagan Plans New ABM Effort," *Science,* vol. 220, Apr. 8, 1983. More recently, the Defensive Technologies Study Team, headed by former NASA Administrator James C. Fletcher, has been reported as concluding that "a space-based [ballistic missile defense] system may also require a continuous manned space presence . . . . Both cost and effectiveness may justify manned systems . . . Development of a repair and refurbishment system may be the key to operational and economic viability of space-based ballistic missile defense." *AW&ST,* Oct. 24, 1983, p. 50.

[34] Herbert P. Ely, "Impact of the Technology Base on Soviet Weapon Development," *Army Research, Development & Acquisition Magazine,* May-June 1982, pp. 12-13. For a broader look at conditions of Soviet technology see: *Industrial Innovation in the Soviet Union,* Ronald Amann and Julian Cooper (New Haven, Conn.: Yale University Press, 1982). The authors discuss Soviet military technologies in detail, and conclude that they do not have the quality and level of sophistication that those of the United States have. In general, although Soviet industry is slow to respond to new R&D initiatives, the technology lag is smallest in the defense and space sectors.

Hampered by a lack of precise instrumentation and sophisticated engineering techniques, Soviet space designers frequently take a "brute-force" approach to problem-solving.[35] Although this approach has obvious drawbacks, it does tend to impose—in contrast to the U.S. system of single-unit production—an economy of operation through the exploitation of continuing production of less complex hardware. Lastly, there is a consensus that an uneven research and development base, poor quality control, and poor quality assurance has impeded Soviet space development on many fronts.[36]

Evidence for these evaluations is provided by the mixed results from lunar probes and interplanetary exploration. Crossing the relatively short distance to Earth's neighboring Moon, Soviet vehicles were generally successful in achieving soft landings, trekking across the lunar terrain, and returning samples of the Moon's surface directly back to Earth. Four-month dashes to the planet Venus resulted in significant Soviet success in landing vehicles and operating their sensors for brief periods on the surface of that extraordinarily inhospitable world.

By contrast, 9-month journeys to Mars have met with repeated failure, and no attempts have been made to probe Mercury, Jupiter, and Saturn. The outer planets in particular, the subject of intense scrutiny by U.S. space vehicles, have so far remained beyond the reach of Soviet probes. The rather limited time during which important systems aboard Soviet spacecraft remain operational is still a major limitation. This weakness also appears in spaceflights with Soviet crews, who have been able to keep Salyuts operational by undertaking unscheduled maintenance and repair.

As these operations of Soviet spacecraft are reviewed, certain limitations become apparent:

Salyut.—Although Salyut is smaller than currently proposed U.S. concepts, it has accommodated Soviet crews for as long as 211 days. Attachment of a Cosmos 929-type module should markedly improve living conditions.

Salyut cannot communicate via line-of-sight circuits directly with Earth stations (in the Soviet Union) during every one of its 15 or 16 daily orbits. On those orbits when communication is not possible, the cosmonauts sleep, and telemetry, communicated *via* shortwave circuits, is sometimes used to monitor basic onboard systems. Even during the in-contact orbits, the crew can communicate with Earth stations on Soviet territory for only 25 minutes out of every 90.

Compared with scientific equipment proposed for any future U.S. "stations," Soviet scientific equipment is low in weight and used sporadically; just a small portion of it is replaceable. The station itself can generate 4 kW of power, Cosmos 1443 contributed 3 kW from its own solar panels while it was attached to Salyut, and additional modules may be expected to do likewise. The low return-weight of equipment transported back to Earth via Soyuz T is one constraining factor; because of the delay in returning photographic film to Earth, its use, rather than reliance on advanced electronics, for remote sensing of the Earth is another (although the installation of live television transmission equipment aboard the latest Salyut has partially overcome this limitation).* The life-support system requires regular deliveries of drinking water and supplies for purifying the cabin atmosphere.** The current configuration requires that Salyut be refueled through its aft docking port.[37]

Soyuz T.—This vehicle, like the original Soyuz, is a reliable, though relatively unsophisticated, spacecraft. Its onboard computer has no backup. The latest mission of cosmonauts aboard Salyut 7 demonstrated an operational lifetime of Soyuz T, while attached to the station, of 150 days. Because the Soviets are reluctant to land Soyuz T in the water or at night, they impose strict constraints on the duration and scheduling of its flights. Yet, they have repeatedly demonstrated the ability to deviate from these conditions when necessary. No spacecraft, of course, can land without restrictions. Indeed, the U.S. Space Shuttle Orbiter operates with even greater restrictions than Soyuz. Major modifications of the U.S. craft would be required if its staytime in orbit were to approach that of Soyuz T.

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[35] Ursula M. Kruse-Vaucienne and John M. Logsdon, *Science and Technology in the Soviet Union—A Profile* (Washington, D.C.: Graduate Program in Science, Technology and Public Policy, The George Washington University, 1979), pp. 3-7.

[36] Even though impediments exist, can they be circumnavigated by a concentrated scientific thrust? See, for example: John W. Kiser, III, "Technology: We Can Learn a Lot From the Soviets," *The Washington Post*, Aug. 14, 1983, pp. C1, C4. See also: Malcom W. Browne, "Soviet Science Assessed as Flawed But Powerful," *The New York Times*, May 20, 1980, p. C-3, which describes the buildup of the Soviet science work force and its potential for scientific surprise.

*App. A.

**Some water is recycled aboard Salyut, a capability that U.S. spacecraft do not possess.

[37] For a discussion of rendezvous and docking techniques involving Soyuz T and the Salyut stations, see: *Aviatsiya i Kosmonautika*, 1979, pp. 36-39, translated in JPRS 74805 Space No. 1, Dec. 20, 1979.

General

In order to minimize one of these deficiencies, the Soviet Union, according to a plan lodged with the International Frequency Registration Board in 1981, intends to operate a system called the Eastern Satellite Data Relay Network (ESDRN), which will employ radiofrequencies similar to the U.S. Tracking and Data Relay Satellite System (TDRSS). The Soviet system would allow reliable, nearly continuous communication with Salyut stations and other spacecraft in low-Earth orbit, commencing perhaps as early as December 1985.

Despite the fact that the Soviet technology base advances more slowly and still remains, in most instances, less sophisticated than that of the United States, it is not suggested that these factors seriously inhibit what appears to be a continuing and expanding set of objectives for productive operations in space, made possible, in part, by people aboard Salyut-class facilities, and determined by what the Soviets consider valuable. Resupply, repair, and service functions, for example, are often performed by cosmonauts, who were a key factor in the longevity of Salyut 6. The Soviets regard the adaptability of human beings as a form of insurance that permits continuous and variegated space station operations.[38]

Whereas the U.S. program from its inception was heavily influenced by the high visibility of the Apollo program and the continuing presence of test pilots, who insisted that astronauts be "in the loop" whenever possible, the Soviet program at the outset was heavily influenced by the Institute for Automatic Control, which obviously had a different orientation. However, the same unreliability of automated equipment that has plagued the Soviets' long-duration planetary probes has made the human presence an essential element in the Salyut program. As a result, the Soviets have gone far in discovering how the attributes peculiar to human beings may be put to effective use in conducting unforeseen as well as planned activities in the course of maintaining and operating a space station.[39] Their growing fund of experience supports and in turn is supported by two related requirements of their ideology and their judgment of their national security interests: that they begin "the inevitable socialist expansion into space," and that they maintain and enhance their national prestige. These factors have resulted in what should be appreciated as the cultivation of the human presence in space.

The Soviets have claimed that people stationed in space can improve the effectiveness of Earth observations. After a period of adjustment of a few weeks, cosmonauts report both improved visual acuity and enhanced perception and differentiation of color, making it possible for them to identify land features and ocean phenomena (e.g., the presence of schools of fish) that were not expected to be visible from low-Earth orbit. These findings have been pursued in real-time aboard Salyut space stations.[40] [41]

In support of the human presence, the Salyut stations have served as medical laboratories in which the occupants have completed comprehensive programs of biomedical and life-science research. Much of this data-gathering is dedicated to answering the following questions: Do long spaceflights result in unacceptable psychological effects and produce harmful physiological alterations of the human body? If so, can these effects be countered? In search of answers, the Soviets are planning in-flight missions that would entail stays up to 1 year for cosmonauts.

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[38] G. T. Beregovoy, et al., *Experimental Psychological Research in Aviation and Cosmonautics* (Moscow: Navka Press, 1978).

[39] G. T. Beregovoy, et al., "Research in Space Psychology," *Psikhologicheskiy Zhurnal*, 3(4), July-August 1982, pp. 160-167. (In English, JPRS *Space*, Nov. 19, 1982, pp. 17-30.)

[40] Jerry Grey, *Beachheads in Space: A Blueprint for the Future*, New York, 1983, p. 42.

[41] Personal communication from Chris Dodge, Science Policy Research Division, Congressional Research Service, Washington, D.C., *re* U.S.-U.S.S.R. Working Group on Space Biology and Medicine, meeting of November 1981, Uniformed Services University of the Health Sciences (USUHS), Bethesda, Md.

Special exercise and diet regimes are being employed to counter changes in cardiovascular tone and muscle systems during flight and to facilitate the subsequent readaptation to gravity. Some changes such as the loss of red blood cells have been found to be self-limiting and subsequently reversible. Others, although decreasing in rate over time, may not entirely level off. In particular, osteoporosis, the loss of calcium from bone, may pose a formidable problem in the context of flight durations of a year or more in the absence of gravity.[42] [43] Extensive ground-based studies employing simulations of weightlessness (including bed rest and water immersion) are augmenting inflight research.[44]

Medical studies of the cosmonauts, supplemented by onboard diagnostic equipment to monitor their overall health on long flights, continue to be given a high priority aboard Salyut. Certain countermeasures have been designed to maintain good health and high performance during prolonged spaceflight. The most demanding of these is exercise, which consumes an average of 2.5 hours during each day in space and involves the use of specialized gear as well as conventional exercise devices.

The Soviets have devised a comprehensive psychological support program, including the transport of letters and news to Salyut crews and frequent two-way video communication with families and research counterparts on the ground. These measures have been instituted to counter the cosmonauts' isolation and heavy workload.

One challenging goal is a closed life-support system aboard Salyut that would generate water and air and produce food, independent of external supply.[45] [46] A complete growing cycle of higher order plants has been evaluated aboard Salyut, as has control of plant diseases and use of vegetables and herbs as food for human consumption.* Creation of partially closed ecological systems may conceivably lead to completely closed systems, suitable for flights of 2 years or more. Designed in accordance with biomedical information derived from past Salyut flights, these closed systems could be implemented for eventual flight to the Moon and neighboring planets; such systems might also lead to substantial cost reductions in Earth orbit operations.

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[42] Arnauld E. Nicogossian and James F. Parker, Jr., *Space Physiology and Medicine*, BioTechnology Inc., NASA Headquarters contract NASW-3469, Washington, D.C., September 1982, pp. 20-24.

[43] The Soviets themselves seem undecided about whether very long-term weightlessness will be a general problem. Cosmonaut Georgi Gretchko is quoted (in "Soviets Unveil Space Station Plans," by Peter Smolders, *New Scientist*, June 30 1983, p. 944) as saying of a possible trip to Mars: "Your heart and entire organism would have become so accustomed to living in space that you would never be able to stand life on Earth again." On the other hand, see Grey, op. cit., pp. 41-42: "One of the cosmonauts, Valery Ryumin, spent a full year in space (he served on the 175-day and 185-day flights aboard Salyut 6), and was in excellent physical condition after both flights. He walked comfortably only one day after returning to the oppressive [*sic*] gravity of Earth, and was jogging happily on the third day. After exhaustive studies of the returned cosmonauts, the Soviets' bioastronautics mentor Oleg Gazenko concluded, 'I believe that humankind can be as happy in space as on Earth.' "

[44] Arnauld E. Nicogossion and Courtland S. Lewis, *A Critical Review of the U.S. and International Research on Effects of Bedrest on Major Body Systems*, Biotechnology, Inc., NASA Headquarters contract No. NASW-3223, Washington, D.C., January 1982.

[45] I. I. Gitelson, et al., *Closed Ecosystems as the Means for the Outer Space Exploration by Men (Experimental Results, Perspectives)*, IAF-81-164, presented in Rome, Italy, Sept. 6-12, 1981.

[46] Y. Y. Shepelev, "Biological Life-Support Systems," ch. 10 of *Foundations of Space Biology and Medicine*, vol. III: Space Medicine and Biotechnology, M. Calvin and O. G. Gazenko (eds.), NASA, 1975. NASA SP-374, pp. 224-308.

*Borage was grown from seedlings to leaf stage, and spring onions from bulbs to maturity.

Future Directions

The Soviet Union's Salyut space stations have formed the backbone of an ambitious and expansive program involving human beings in space. The ideological underpinning of Salyut is the desire to project and maintain an image of scientific, technological, and industrial world leadership in space. Overall, the Soviet approach toward implementing these goals has been one of cautious advance—a step-by-step evolution consistent with an often-stated, long-term goal of spreading Soviet influence into near-Earth space and beyond. As was the case for the U.S. Apollo program, the Soviet effort does not appear to be predicated on near-term economic benefits.

The last 5 years have witnessed a growing maturity and confidence in Soviet spaceflight planning and conduct. Present Soviet activities with Salyut are approaching the establishment of a permanent human presence in low-Earth orbit.[47] Whether or not continuous human occupancy is established soon, the Soviet Union can be expected at least to maintain and probably to expand human activities in space. The Salyut space station is anticipated to remain the central element for space operations involving people, although several new programs may augment the station's use and enhance the range of future Soviet options.

Three New Initiatives

Soviet planners appear to be looking at three new initiatives: modular space stations, heavy-lift expendable boosters, and reusable launch vehicles. President Brezhnev was apparently a strong supporter of space expenditures; President Andropov's views are not fully known.[48] Although appraisals of Soviet spending are difficult,[49] one estimate puts the overall cost of the Soyuz/Salyut program during the 1970's at nearly $40 billion (in 1980-adjusted dollars). That is approximately the cost of the entire U.S. Moon Landing program—from the first Mercury suborbital flight to the final Apollo 17 Moon landing and return.[50] Moreover, the cost to develop, launch, and maintain Salyut 6 during its nearly 5-year tour-of-duty probably exceeded $9 billion (in 1980-adjusted dollars).[51] As in the United States, the economic climate in the Soviet Union might well dictate the scope, scale, and timing of any new Soviet space initiative.

Modular Space Stations

A modular station could be composed of five to eight units, separately launched and assembled in orbit. These plans are well within current Soviet capabilities. Indeed, Soviet sources have identified Cosmos 929-class modules as prototypes:

> . . . of the kind that will be linked together to form a multi-purpose orbital station. One of the modules will be a fitted-out laboratory, others will perform purely technological duties. There will also be observatory modules and whole plants for manufacturing products in zero-g. Lounge modules will be living quarters for cosmonauts to take a rest after the heavy workload they will handle in space. . . . Each station can easily be modified by changing modules to fit changing needs of the mission . . .[52]

Within a constellation of such modules, Soviet cosmonauts could begin to live in orbit more comfortably and more productively. A modular space station could be the beginning of a usefully permanent human presence in space. Among other possibilities, the crew of a large, well-equipped station would no longer have to be limited to broadly trained cosmonauts. Technicians with particular specialties could be included in the station's complement. In any case, a large modular station would allow human beings to achieve a more normal, leisured, and productive life in space than has hitherto been possible.

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[47] Rolf Engel, "Soyuz and Salyut: Stepping-stones to a Permanent Soviet Space Station?" *Interavia*, February 1982, pp. 173-177.

[48] According to one Western source, no major change in the Soviet determination to expand in space is to be expected. See: Theo Pirard, "Russia's Future in Space," *Space Press*, June 1983, pp. 16-17.

[49] See, for example: "Estimating Soviet Military Spending—An Arcane Art With Political Overtones," by Michael R. Gordon, *National Journal*, June 26, 1982, pp. 1140-1141. Gordon discusses the controversy surrounding U.S. estimates of Soviet military spending which are used to justify increased American military budget requests.

[50] Engel, op. cit., p. 175. These estimated costs for the Soviet program include expenditures for investment, infrastructure, and development.

[51] Saunders Kramer, "Salyut Mission," in Letters to the Editor, *AW&ST*, Oct. 27, 1980, p. 76.

[52] Dr. Feoktistov, quoted in DST-14005-022082.

Heavy-Lift Expendable Boosters

Currently, Salyut operations are carried out using two types of launch vehicles. The "A" series booster, which provides over 400 tonnes of thrust at liftoff, is the workhorse of the Soviet launcher family.[53] Variants of this booster are used to loft Soyuz, Soyuz T, Progress, and other vehicles. This standard launch vehicle, minus its upper stage, was used to orbit Sputnik 1 into space in 1957—an indication of its reliability and longevity.[54] "D" series boosters, called "Protons," have launched Salyut space stations and Cosmos 929-class modules without cosmonauts onboard. The Proton's thrust at liftoff equals about 1,000 tonnes. There are also "C" and "F" series boosters which meet other requirements, but those of the "B" series have been phased out.

Under development, according to reports reaching the West, is a new booster in the "G" series capable of producing up to 5,000 tonnes of thrust at liftoff. Previous boosters in this series were apparently destroyed in three inaugural attempts (1969, 1971, and 1972): one exploded on the launch pad and two exploded in flight. Similar to the U.S. Saturn V, the redesigned G booster, possibly carrying cryogenic upper stages, is several years away from operational status, though test flights could occur between 1984 and 1986. A Pentagon analysis claims the booster will be capable of putting very heavy payloads into orbit (180 to 210 tonnes)—six to seven times the payload weight of the U.S. space Shuttle.[55]

Some believe the new "G" series booster will lead to the long-awaited Soviet attempt to put cosmonauts on the Moon. Others believe it will be used to orbit very large electromagnetic weapons. The new booster could also propel a 90-tonne station into orbit, to be occupied by a dozen or more crewmembers by the end of the decade. Such facilities might, in some respects, be more attractive than space stations built from smaller modules. With relatively small-sized modules, such as the Cosmos 929-class, for example, there may be as much as 30 percent redundancy of hardware for rendezvous, docking, propulsion, electrical power, structural support, and the like. In a larger station, the weight of this otherwise employed hardware could be used instead for additional instrumentation, living quarters, manufacturing facilities, and other productive equipment. All of these uses could be fulfilled by such a launcher. As an alternative to developing such a "G" series launcher, the Proton booster might be upgraded to carry cosmonauts. This choice would allow some modest improvements and avoid the risks inherent in developing a new launcher.

Reusable Vehicles

The Reusable Space Plane.—Speculation concerning a Soviet version of the U.S. Dyna-Soar has been fueled by two Cosmos flight tests, each apparently designed to evaluate the aerodynamic and reentry characteristics of a winged space plane, weighing about a tonne. These missions—Cosmos 1374 on June 3, 1982, and Cosmos 1445 on March 15, 1983—flew identical trajectories; each was sent into space for a 2-hour test from the Kapustin Yar launch site near Volgograd, orbited the Earth, and landed in the Indian Ocean. A seven-ship Soviet task force supported both retrieval operations. Photographs of the Soviet recovery of Cosmos 1445, released by the Royal Australian Air Force, indicate the craft is of a lifting-body/blended-wing design.[56] Some Western experts contend that the recovered vehicles are prototypes designed to provide reentry data for a larger 10- to 20-tonne version which would carry a crew. (By contrast, the U.S. space Shuttle weighs approximately 100 tonnes.) The Soviet tests have been likened to the U.S. Asset program of the early 1960's, which made use of several

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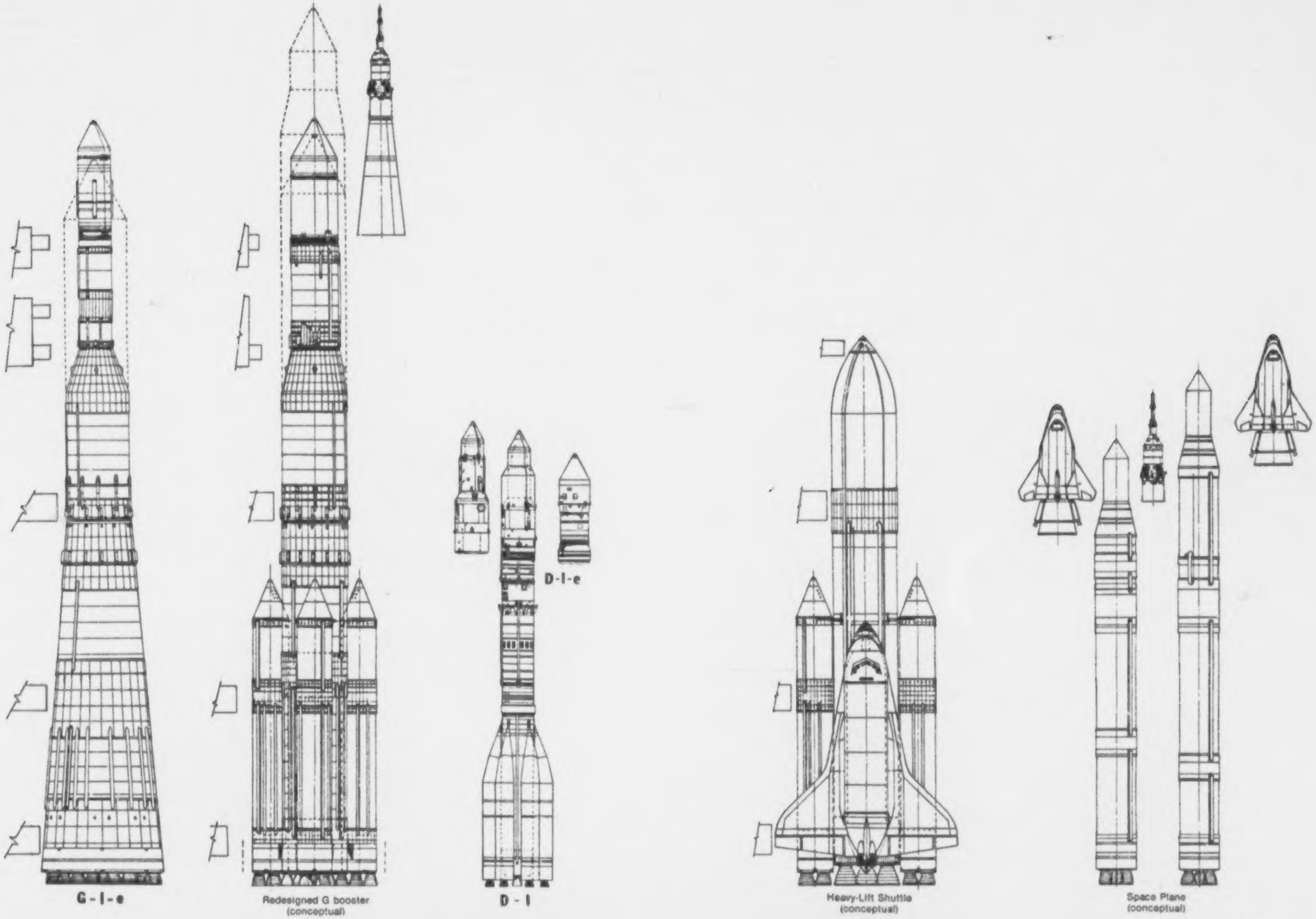
[53] Appendix A describes this booster in more detail. See also Glushko, Valentin, Petrovich, "Development of Missile Construction and Cosmonautics in the U.S.S.R.," *Mashinostrayeniye* (Moscow: Machine Industry Publishing House, 1982), p. 66.

[54] James Oberg, "Beyond Sputnik's Booster," *Omni*, October 1982, pp. 22, 189.

[55] *Soviet Military Power* (Washington, D.C.: U.S. Department of Defense, 1981), pp. 79-80.

[56] See the following: Craig Covault, "Soviets Orbit Shuttle Vehicle," *AW&ST*, June 14, 1982, pp. 79-80; "Soviets Launch Winged Spacecraft," *AW&ST*, Mar. 21, 1983, p. 18; "Soviets Recover Spaceplane in Indian Ocean," *AW&ST*, Mar. 28, 1983, p. 15; and "Soviets Recover Spaceplane," *AW&ST*, Apr. 4, 1983, p. 16. See also: U.S. Department of Defense, *Soviet Military Power*, March 1983, pp. 66-68.


G-I-e
Redesigned G booster (conceptual)
D-I
D-I-e
Heavy-Lift Shuttle (conceptual)
Space Plane (conceptual)

Credit: ©C. P. Vick, 1983

Projected Soviet Space Vehicles, the redesigned G booster, the heavy-lift shuttle, and the space plane, compared with earlier boosters, the unsuccessful G-1-e and the current D-1

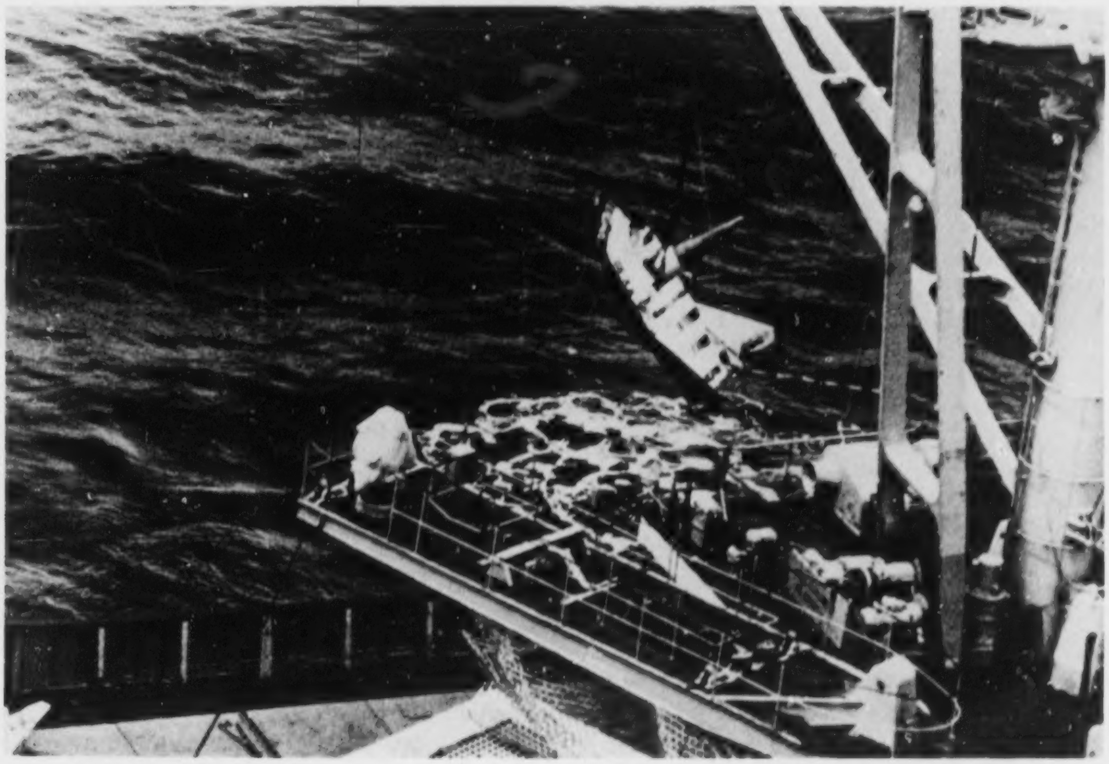


Photo credit: Australia Department of Defence

Recovery of Cosmos-1445 by the SSVRS 201 YAMAL is believed to be a quarter-scale testbed version of the Soviet space plane

gliders on suborbital flights into the Atlantic, to gather heating and structural load information on winged space vehicle designs.

Some Western observers believe this program may have begun as early as 1976. Drop tests of the Soviet space plane from aircraft, akin to those carried out in the U.S. space Shuttle program, have been reported.

The Soviet space plane is expected to be capable of ferrying three persons between the ground and the Salyut station or other platforms in low-Earth orbit. It should be able to provide a means of rapid evacuation from the station and sufficient cross-range to allow landing at any major airport. However, its design may make little, if any, cargo space available, thus affording no solution to the Soviets' inability to return heavy payloads from space stations to Earth. Although less versatile than the U.S. Shuttle, its greater simplicity might be well-adapted to quick launch and turnaround as well as rapid response to occasional reconnaissance requirements. Operation of the vehicle may begin within 2 to 3 years.

The Reusable Heavy-Lift Shuttle.—According to an assessment by the Department of Defense, the Soviet Union is apparently building a "heavy-lift" space shuttle similar in design to the U.S. Shuttle but capable of lofting twice as much payload into orbit. As detailed in a 1983 report on Soviet military power,[57] [58] the heavy shuttle, like the U.S. Shuttle, will be a delta-winged orbiter mounted on an external tank with strap-on boosters. However, its ratio of payload weight to total vehicle weight is judged to be higher than that of the U.S. vehicle, and the specific impulse of its liquid-fuel strap-on boosters could be higher than the Shuttle's solid-fuel engines. In addition, the U.S. Shuttle carries 40,000 lbs of main engines and propulsion equipment on the Orbiter itself, whereas the Soviet shuttle would carry them on its main tank. This general configuration, whereby the Soviet shuttle would not have to recover its high-energy main engines, would result in a large payload bonus, though this advantage would have to be weighed against the cost of replacing the (unrecovered) engines. Overall, although its precise configuration and propellants are not known, the Soviet shuttle, with liquid strap-on boosters, could provide a payload capability of perhaps twice that of the 65,000 lbs of the U.S. Shuttle.[59]

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[57] *Soviet Military Power,* 2d ed. (Washington, D.C.: U.S. Department of Defense, March 1983), pp. 64-69.

[58] Craig Covault, "Soviets Building Heavy Shuttle," *AW&ST,* Mar. 14, 1983, pp. 255-259.

Although the smaller space plane has been undergoing tests for several years, the heavy-lift shuttle design is relatively new and would require, perhaps, a decade of development and testing before it would be ready for regular use. Advanced versions of the vehicle could evolve into a two-stage, fully reusable system.[60] [61] At the Tyuratam spaceport near the Aral Sea, where Soviet cosmonauts are often launched, a large runway has been built and could be used to support operations for either type of reusable spacecraft.[62]

General Considerations

Although both types of Soviet reusable spacecraft may be realized in the relatively near future, Western experts disagree on the roles these vehicles might play with cosmonauts aboard. Some have suggested that the space plane could serve the Soviet military as a "space fighter."[63] Others think that the Soviets plan to use it as a replacement for Soyuz T vehicles. The heavy-lift shuttle, on the other hand, could well have an important role in boosting a new and larger generation of space-station modules into orbit.

The Soviets have bitterly criticized the U.S. space Shuttle as evidence of the "militarization of space" despite the official U.S. position that the craft is not a weapon. Soviet criticism may arise from a genuine fear of its use for military operations, or it may be a smoke screen to be maintained only until the Soviet Union can unveil a similar vehicle.[64] Soviet protests against U.S. military reconnaissance satellites, for instance, subsided once the U.S.S.R. had launched comparable spacecraft.

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[59] See Picard, op. cit. It should be noted, however, that previous Soviet practice has been to rely on space structures that, relative to comparable U.S. structures, are heavy. If this practice is continued in the heavy-lift shuttle, and if this vehicle does indeed rely exclusively on liquid propellants, then a payload capacity double that of the U.S. Shuttle would imply a thrust at lift-off of some 3,000 to 4,000 tonnes.

[60] Craig Covault, "Soviets Developing Fly Back Launcher," *AW&ST*, Nov. 6, 1978, pp. 19-20.

[61] For further views on a Soviet space shuttle system, see: "A Soviet Space Shuttle?" by Kenneth Gatland, *Spaceflight*, September-October, 1978, pp. 325-326. Also, "The Soviet Space Shuttle Program," by Lt. Carl A. Forbrich, *Air Univ, Review*, May-June 1980, pp. 55-62, and "The Soviet Space Shuttle: Sifting Fact From Rumor," by James Oberg, reprinted in *Insight*, the newsletter of the National Space Institute, June-July 1980, pp. 4, 9.

[62] Pictures of the runaway have now appeared in *AW&ST*, Mar. 21, 1983, pp. 20-21.

[63] "Soviet Militarization of Space," *Air Force Magazine*, March 1982, p. 42.

[64] Soviet sensitivities as to the military usefulness of the U.S. Space Shuttle and its potential for sparking Soviet "technological inferiority" are evidenced in: *Soviet Elites—World View and Perceptions of the U.S.*, by G. Guroff and Steven Grant, Office of Research, International Communications Agency, R-18-81, Sept. 29, 1981, p. 17. Report observes:

> The U.S. space shuttle, in particular, seems to have left Soviets, including some at the highest levels, almost speechless. When they saw on television (private showings) what the U.S. had done, it was clear to many that their erstwhile "lead" in the manned space race had disappeared, and that their own program was years behind that of the U.S. Given the wide publicity of Soviet space efforts, many Soviets felt until then that the U.S. had all but abandoned space to the Soviet Union.
>
> Many believe that they are incapable of doing what the U.S. has done with the shuttle. This feeling translates for most Soviets into the further belief that if the U.S. wants to, it can change the military balance in its favor almost overnight—that it can pull some weapon/rabbit out of its technological hat at any moment and leave the Soviet Union far behind in the arms race.

Soviet concern regarding U.S. intentions to develop a space weapons capability could be amply fueled by such documents as: *High Frontier—A New National Strategy*, a Project of the Heritage Foundation, Washington, D.C. 1982, which calls for, among other elements, a military "high performance spaceplane" for inspecting or retrieval of "suspect" space objects.

American perceptions of the Soviet military presence in space is typified by: "Twenty-five Years After Sputnik—The New Soviet Arms Buildup in Space," *The New York Time Magazine*, Oct. 3, 1982, pp. 30-34, 89, 92-93, 98, 100.

Impact on Foreign Policy

The Soviet Union's space program is intended to demonstrate, inter alia, what can be achieved under its form of government. To this end, the Soviets have made political capital out of their guest cosmonaut program: a number of cosmonauts from Soviet-bloc countries—Czechoslovakia, Poland, East Germany, Bulgaria, Hungary, Vietnam, Cuba, Mongolia, and Romania[65]—were ferried to Salyut 6 for short-duration working visits. A French spationaut was transported to and from Salyut 7. Preparations are underway to include a crewmember from India in early 1984, and other countries may be invited to participate in future missions. How valuable is the guest program? At a minimum, it supports Soviet propaganda aims, and the scientific exchange, particularly with the French, may be of significant value. In any case, the Soviets clearly believe that the program is worth the relatively small investment required.

These international activities suggest the Soviets have decided to make their space program somewhat more open. Recently, they have also begun to announce some launch dates and to allow outsiders to observe payload processing, to view launches, and to access scientific data more quickly.

In contrast to the United States, the Soviet Union, in the view of some, is much more aggressive in deploying its space program as an important element in its foreign policy. Increasing openness may be the forerunner of greater cooperative efforts, particularly in the use of more instrumentation from Eastern European sources. The cooperative Soviet-French venture to probe Venus and Halley's Comet, for example, will incorporate more sophisticated technology than the Soviets have previously used, thus increasing its chance of success.[66]

Whereas the Apollo-Soyuz Test Project (ASTP) came to fruition as a product of detente, similar joint U.S.-Soviet ventures involving space stations are viewed by many as out of step with current political realities. Others suggest that such ventures are technically logical and diplomatically feasible.[67] There is also a possibility that cooperative space ventures could become polarized: the Soviet Union might increase its working relationships with Eastern European countries and, perhaps, France, while the United States works with Japan, Canada, and Western Europe.[68] Future Salyuts could incorporate "internationalized" modules dedicated to specific scientific research or commercial application.

The impact of an evolving Soviet space station program on U.S. space policy is unclear. Many observers agree that a U.S.S.R. pronouncement that a "permanent presence in space" had been achieved would do little to reshape U.S. civilian space objectives. Even bolder announcements of Soviet intentions to send human beings to the Moon or to traverse interplanetary distances to establish a human presence on Mars, might have little influence on U.S. pursuits. Creation of a significant and obvious military installation in orbit, however, might well dictate an American response in kind.

In the end, a U.S. response to any new Soviet space project would be heavily influenced by public opinion and the circumstances of that moment. It is impossible to predict with much assurance just what Soviet activities might trigger an important American reaction.

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[65] The last six are in Cyrillic alphabetical order. See J. Oberg, *Red Star in Orbit*.

[66] "French, Soviets Weigh Venus Mission," *AW&ST*, Nov. 22, 1982, pp. 79-80.

[67] See, for example, "Hitch Up With a Red Star," James Oberg, *OMNI*, March 1982, p. 20.

[68] "NASA Mulls International Effort on Space Station," *AW&ST* Mar. 1, 1982, pp. 20-21.

Conclusion

In any characterization of the future of the Soviet space program, caution is the rule. Western forecasters during the past 5 years expected a more dynamic effort than the Soviets actually put forth. Still, the Soviets have shown considerable perseverance, and their predictions about even bigger space stations—capable of housing "large collectives" rather than small crews—should be taken seriously. Modularized space facilities—carrying equipment for astronomical, physical, and chemical experiments, and for technology development purposes, adapted for multidisciplinary programs for both civilian and military purposes—can be expected.[69] It is possible that useful and marketable products and services could be provided. Such stations, situated in various orbits, would be a straightforward extension of demonstrated Soviet capabilities. Eventually, these same facilities could involve international teams.

With a sufficient commitment of resources, the Soviets may be able to maintain a continued human presence in space through the use of heavy-lift launchers and/or expanded use of currently available boosters. A shuttle-type vehicle would permit routine access to platforms in near-Earth orbit. A large Salyut complex could serve as a space transportation node or base camp.

As recently as late November 1983, the Soviet newspaper *Pravda* asserted that the main thrust of Soviet cosmonautics is "the creation of [sophisticated] orbital manned complexes, which can be improved during lengthy use and be reconstructed depending on the nature of the tasks being tackled."[70] The next step in the Soviet space program will aparently be "the transition from long-term orbital stations regularly visited by replacement crews to a multi-team, permanently manned orbital complex.[71]

From a permanent foothold in near-Earth orbit, the next step might be an extension to geostationary orbit. Soviet scientists have argued that a series of orbital stations might one day stretch for hundreds of miles in a given orbit.[72]

Salyut operations are one step in the Soviet drive toward mastery of space. It is quite conceivable that, by the end of the century, they cound put cosmonauts on the Moon.[73]

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[69] Comments of Anatoly Skripko, Science and Technology Attaché to the Soviet Embassy in Washington, D.C., at a luncheon of the American Astronautical Society, Feb. 12, 1982. See also "Soviets Initiating Program on Modular Space Station," by Craig Covault, *AW&ST*, July 20, 1981, p. 22; and "Soviets Move Toward Space Operations Center," James Oberg, *Aeronautics and Astronautics*, May 1982.

[70] Quotation from *Pravda*, Nov. 25, 1983, appearing in *Aerospace Daily*, Dec. 1, 1983, p. 155.

[71] *Pravda*, Nov. 28, 1983, quoted in *Aerospace Daily*, Dec. 1, 1983, p. 155. The article continued as follows: "*Pravda* said the size of such a complex 'will be impressive even by the standards of construction on Earth. For instance, the parabolic antenna alone should have an effective aperture . . . [o]n the order of 300-350 meters. In addition, it must be geared to a long period of operation—15-20 years as a minimum.'

"*Pravda* said that '[t]oday, this complex is conceived as a unified system of large-scale installations in orbit at an altitude of 200-400 kilometers, linked to Earth by freight and passenger transport spacecraft. The complex will include specialized scientific research laboratories, comfortable housing modules, powerful energy installations, a refueling station, repair workshops, and even construction sites for producing and installing standardized construction components. The real potential of orbital flight for the *ad hoc* solution of urgent national economic tasks will also be expanded many times over.' "

[72] Yuri Zaitsev, "Orbital Stations—The Present and Future," *Moscow News*, #45 (2825), Nov. 19-26, 1978, p. 11.

[73] "The Soviets think that in about 20 years a journey to Mars may be possible. By this time, spaceships may incorporate centrifuges that simulate the conditions of living under gravity." Smolders, op. cit., p. 944.

Postscript

According to accounts published in U.S. newspapers on October 12, 1983,[74] the Soviets announced a nearly disastrous setback when an A-2 rocket, bearing a Soyuz T and two cosmonauts, exploded on a launch pad at the Tyuratam cosmodrome. Apparently, just prior to scheduled liftoff, a fire was detected at the base of the launch vehicle, and the launch escape system was triggered, either by automatic failure detection circuitry, the blockhouse crew, or the cosmonauts themselves. The launch escape tower rocket ejected the Soyuz orbital module and the descent module carrying the cosmonauts moments before the booster exploded beneath them. Subsequently, the descent module was separated from the orbital module and parachuted to Earth. The escape rocket subjected the cosmonauts to a high velocity, high G, escape trajectory, and the landing impact velocity was substantially higher than the normal 3.3 feet per second. Both may have sustained some injuries. This two-man crew was to have made a week-long resupply visit to the two cosmonauts who have been aboard Salyut 7 since June 28, 1983.[75]

This accident did not seem to have placed the crew aboard the Salyut in any great danger because they were resupplied by Progress 17 in mid-August and Progress 18 in October and because they were resupplied by Progress 17 in mid-August and Progress 18 in October and because their Soyuz T-9 was still capable of returning them to Earth. In addition, the Soviets have at least three other (undamaged) launch pads at Tyuratam, and almost certainly have another Soyuz T and an A-2 booster which could have been integrated and readied for launch on short notice. The degraded condition of Salyut 7, however, adds additional uncertainty for future missions. The Soviets have announced that the most recent crew of cosmonauts returned to Earth on November 23, 1983, after a mission of 150 days.

Coincidentally, NASA has had to postpone the first flight of Spacelab aboard the Shuttle because "a liner that protects the lowest part of one of the [reusable] solid-rocket engines from heat" was almost burned through during the previous Shuttle flight.[76] If the flame had burned through part of the engine in flight, the Shuttle would have become aerodynamically unstable some 2 minutes after launch; the result could have been a catastrophe.

The U.S.S.R. accident and the U.S. near-accident indisputably show that space operations are still hazardous, even with systems that have been flight-proved time after time.

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[74] *Washington Post,* Oct. 12, 1983, p. A-9; *New York Times,* Oct. 12, 1983, p. A-7.

[75] For a thorough discussion both of the accident and of the failure aboard Salyut 7, see the article "Explosion, Leak Cripple Salyut 7 Effort," *AW&ST,* Oct. 10, 1983, pp. 23-26.

[76] *The Washington Post,* Oct. 13, 1983, p. A-15.

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Appendixes

Appendix A:

The Soviet Salyut Space Program: Space Station, Spacecraft, Support and Training Facilities

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Material provided to OTA by Dr. Balayan, Vice Chairman of the Intercosmos Council of the U.S.S.R. Academy of Sciences.

The Salyut Orbital Scientific Station

The creation of the Salyut orbital stations is an important stage in the development of Soviet cosmonautics, intended to increase the length of both manned and unmanned flights.

The total mass of the orbiting scientific complex, including two transport ships, is 32,500 kilograms (kg); the mass of the space station in orbit is 18,900 kg, the mass of the transport ship in orbit is 6,800 kg.* The dimensions are as follows: 1) total length docked with two transport ships 29 meters (m), 2) station length 15 m, 3) maximum station diameter 4.15 m, and 4) maximum transverse station dimension with solar panels open 17 m.

More than 20 portholes are provided for the conduct of scientific experiments, visual observation, and still and motion picture photography from the compartments of the station.

Hatches in the docking units are used to allow the crew to move between the transport ship and the station. After docking, the crew can work and rest both in the compartments of the station and in the transport ships, moving through these hatches.

Terrestrial conditions are maintained in the sections of the station in orbit—the same gas composition, atmospheric temperature and pressure, providing the necessary conditions for the cosmonauts' activities.

Composition and Arrangement of Orbital Station

The station consists of five compartments: transit, operations, scientific apparatus, intermediate, and equipment compartments.

During powered flight the external elements of the transit section and parts of the small-diameter operations section are protected from aerodynamic forces by fairings which are later jettisoned.

The scientific equipment installed in the scientific apparatus section is protected during powered flight by a scientific apparatus cover which is also jettisoned after orbital insertion.

The transit section is bounded by conical and cylindrical (2 m diameter) sealed envelopes.

The passive portion of the docking unit—the "cone" —is installed at the conical end of the section (the active "rod" docking unit is installed on the spacecraft), while the cylindrical portion of the section adjoins the operations section of the orbital unit.

There is a hatch in the conical envelope of the transit section to allow servicing of the station on Earth and to allow the crew to exit into space. The outer surface of the transit section carries:

- antenna of the approach and docking unit;
- optical lamps for orientation during manual docking of spacecraft;
- external television cameras;
- panels with temperature regulation units;
- gas storage cylinders of the life-support system containing air;
- ionic and solar sensors of the station's orientation system;
- handles and restrainers for cosmonauts in spacesuits performing space walks; and
- panels for the study of micrometeorites, contamination of optical surfaces, and properties of rubber and biologic polymers.

The outside of the transit section and the apparatus installed on it are covered with a vacuum-shield thermal insulation to maintain the required temperature conditions.

Within the transit section, which is used as a lock, are spacesuits, panels, equipment and attachment devices to support space walks.

There are seven portholes in the transit section. Some carry instruments for astro-orientation of the station. These instruments, together with the corresponding control panels and knobs which control the orientation of the station, form two control posts (post Nos. 5 and 6).

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*These masses appear to be related to Salyut 6 and Soyuz craft.

The transit section connects to the operations section of the station through a sealed airtight hatch. The operations sections consists of two cylindrical shells (2.9 m diameter and 3.5 m length, and 4.1 m diameter and 2.7 m length) connected by a conical section (1.2 m in length).

The cylindrical shells have spherical ends. The posterior end has a hatch which connects the operations sections with the intermediate chamber.

In the operations section, equipment is arranged along the section forming a common passageway beside the equipment, with instruments and equipment located to the left and right. The instruments and equipment are installed on standard racks which form the frame of the interior.

Most of the monitoring and control systems and scientific apparatus of the station are in the operations section. The apparatus with which the station crew works directly is grouped by functional purpose in five control posts (there are two additional control posts in the transit section, as was mentioned earlier).

Post No. 1 is the central control post of the station, where control of the main station systems is concentrated. It is located in the lower portion of the operations section (in the small diameter area). This post has two working locations equipped with chairs (for restraint), communications equipment, control panels, a lever to control the angular position of the station in space, optical sites of the orientation system, and portholes with no equipment.

To the left and right of the control panel are the regenerator cartridges of the station's gas-mixture support system, as well as the refrigeration and drying units of the temperature control system. Near the forward end of the operations section beyond control panel No. 1 are the gyroscopic instruments of the orientation and motion control system, mounted on a rigid frame.

Post No. 2 (the astropost) is also in the lower, small diameter portion of the operations section, closer to its conical portion. This post is used for astro-orientation and astro-navigation of the station. The post is equipped with communications equipment, an orientation control panel, and astro-instruments (installed on two portholes).

Between post Nos. 1 and 2 in the small diameter end of the operations section is the area where the crew eat and rest. In this area is a table with special devices for heating food. A drinking water container is attached to the table. Along the right side in this area is the system which regenerates water from atmospheric moisture condensate. The cosmonauts obtain hot and cold water from this system. Behind the interior panels on the left side is the onboard computer apparatus. The cosmonauts can perform minor preventive repair of equipment on the table in this area, for which they have a special onboard toolkit available.

Post No. 3 is intended to control the apparatus located in the scientific equipment section. This post is located in the large diameter portion of the operations section in its lower part near the rear end. Control panels, communications equipment, and retainers are installed here.

The instrument zone contains the onboard radio system, radio telemetry system, and power supply system control apparatus. Near the aft end of the operations section on the left and right sides are the crew's bunks, and in the instrument area there are food storage containers.

In the upper portion of the operations section (near the aft end) are two locks for jettisoning the crew's wastes into space. Wastes are collected in special containers and, after they are ejected from the lock chamber, burn up in the atmosphere.

On the aft end of the operations section is the head. It is separated from the remaining portion of the operations section and has forced ventilation. Beside it is a vacuum cleaner, dust filters, storage for water, linens, and other life-support system consumables.

In the forward, larger-diameter portion of the operations section is a system allowing the crew to shower periodically.

Post No. 4 is in the lower central portion of the operations section near the conical shell. Here is the equipment used for most of the medical experiments, still and motion picture cameras, and the scientific apparatus control panel. This post has cosmonaut restrainers and communications equipment.

Near post No. 4 is the system used to prevent ill effects of weightlessness on the cosmonauts. It includes:

- a treadmill and other devices for physical exercise;
- a bicycle ergometer;
- a pneumatic vacuum suit to create low pressure on the lower portion of the body; and
- a muscle tissue stimulation apparatus.

One of the two portholes at post No. 4 carries an MKF-6M multiple-zone survey camera manufactured by Karl Zeis Jena of East Germany with electronics and control panel.

On the left and right sides near post No. 4 are the refrigeration and drying units of the temperature control system, the onboard radio apparatus, electronic units of the orientation system, and station movement control system.

Post No. 7 works in cooperation with the scientific equipment control post and water regeneration system control. This post is located in the central portion of the small diameter operations section.

Control panels are mounted on the interior to the left and right; the cosmonaut who works here is restrained in a reinforced seat.

All control panels and cosmonaut working locations are equipped with internal loudspeaker communications devices and daylight lamps. Other lamps are used to create general illumination in the living space. During still and motion picture photography and television reports, the cosmonauts turn on additional lights to provide the necessary illumination for the cameras.

Most of the outer surface of the small diameter operations section is covered with the temperature control system's radiator. On the left and right sides and in the upper portions of the section are three solar battery panels. Special drives rotate the panels toward the Sun at all times. In the forward portion of the operations section are the solar battery orientation system sensors, which determine the position of the Sun in the forward hemisphere as the station moves. Outside the lower portion of the small diameter operations section are the automatic station orientation instruments (an infrared vertical, solar sensor, television orientation device, etc.). Outside the conical portion of the operations section is a special repeating action cover with electric drive to maintain the temperature of the porthole through which the MKF-6M camera operates.

On the outside of the large diameter operations section are the onboard radio system and telemetry system antennas.

To maintain the proper temperature the body of the operations section is covered on the outside with mats of vacuum shield heat insulation, while the large diameter portion of the section is also covered with a fiberglas cover for protection from aerodynamic heating during powered flight. On the sides of the station are panels with sensors to study the flux of micrometeorites.

The unsealed cylindrical equipment section (4.15 m diameter, 2.2 m length) contains:

- the combined motor installation, including correcting motors and a system of low thrust motors which creates controlled torque to orient the station in space; and
- tanks of fuel.

On the outer surface of the equipment section are:

- the approach and docking radio antennas;
- optical lamps for orientation during manual docking of spacecraft with the station;
- the solar battery orientation system sensors, which determine the position of the Sun in the aft hemisphere (with respect to station flight);
- the onboard radio system antennas; and
- a television camera to monitor docking of transport spacecraft.

The equipment section is thermostatted in flight and has external heat insulation similar to the insulation of the operations section. The equipment section is connected to the end of the operations section; its aft end is connected to the booster rocket.

The scientific apparatus section is in the large diameter cylindrical portion of the operations section. It is a combination of conical and cylindrical shells (maximum 2.2 m diameter). The end of the section is oriented toward outer space and is equipped with a cover.

The intermediate chamber of the station is a sealed section consisting of cylindrical and conical shells 2 m in diameter with a total length 1.3 m. The second docking unit of the orbital station is mounted through the conical section on the intermediate chamber.

The intermediate chamber is used to carry equipment delivered by the transport spacecraft. An air line is laid through it to supply air from the operations section to the transport ship to create a common atmosphere. The intermediate section has two portholes used for visual observation, still and motion picture photography and television reporting.

Systems of the Orbital Station, Their Purpose, and Main Operating Modes

1. Onboard Equipment Control System (SUBK).—The SUBK controls the onboard systems:

- automatically (by a programed timer);
- on radioed command from the Earth; and
- on command of the cosmonauts at the control panels.

The SUBK switches the electric power supply system and protects the power supplies from short circuits, controls the pyrotechnic cartridges which open and deploy external elements of the structure, etc., and outputs information on the results of operations to the cosmonauts' panels and to Earth.

2. Orientation and Motion Control System (SOUD).—The SOUD is intended to orient and control the motion of the space station in automatic and manual modes.

The SOUD includes:

- a sensor apparatus (sensing elements);
  - —solar sensor;
  - —infrared vertical device (IKV);
  - —gyroscopic angular motion sensors;
  - —an ionic sensor;
  - —free three-way gyroscope; and
  - —velocity increment integrator.
- manual instruments:
  - —a wide-angle orienting site;
  - —optical orientors;
  - —an electronic-optical converter; and
  - —an astro-orientor.

- the "Kaskad" apparatus to maintain long-term orbital and inertial orientation;
- the approach electronic apparatus;
- lamps and targets for manual approach and docking; and
- automatic equipment and electronic units.

3. Combined Motor Installation (ODU).—The ODU is intended to create controlled torque around the center of mass of the station by means of low-thrust motors, and to generate power to move the station by means of the high-thrust motors.

The combined motor installation includes:

- correcting motors (two); and
- orientation motors.

The motors are supplied with fuel from two groups of collectors, each of which supplies the motors through three station control panels—pitch, yaw and roll.

4. Command Radio Link.—The system is intended to transmit control commands and settings from the Earth to orbit, trajectory measurements, two-way telephone communications between Earth and the station, and television and telemetry information from the station to Earth.

The system includes receivers, transmitters, antenna-feeder device, a programed timer (PVU), decoder, and other electronics and automation equipment.

5. Television Communications System.—The television system is used to transmit color and monochrome images from the onboard television cameras to Earth and to the onboard television screen (VKU).

The system includes:

- external stationary television cameras (monochrome images);
- the reporting television camera (color);
- the reserve reporting camera (monochrome);
- video monitors (VKU);
- the antenna-feeder devices;
- special lamps; and
- automation and electronic equipment.

6. Telephone Communications System.—The "Zarya" radiotelephone communications system is intended to provide two-way Earth-station and station-spacecraft communications in the ultra-short wave (USW) and short wave (SW) bands. The system includes USW receivers and transmitters, SW receivers and transmitters, and antenna-feeder devices.

To provide loudspeaker communications within the sealed station sections, there are loudspeakers, microphones, and amplifiers at the control posts and working locations.

The transmission of text (alphanumeric) information from Earth to the station utilizes an apparatus with a printer.

7. Radiotelemetry Communications system (RTS).—The radiotelemetry system is designed to collect information and transmit it from the spacecraft to Earth. The station carries two RTS systems; one system is used for service information, the other for information from the scientific and experimental apparatus.

Independent magnetic recorders (MIR) with magnetic tape cassettes are used to record scientific measurements with high sampling frequency. The magnetic tapes are returned to Earth on transport spacecraft.

8. Orbital Control Radio System, Which Performs Trajectory Measurements.

9. Power Supply System.—The power supply system (SEP) provides electric power for all onboard systems of the station, and also charges the buffer batteries (BB) and supplies power to transport spacecraft docked to the orbital unit.

The system includes:

- solar batteries (SB); three solar battery panels are installed on three planes of the station;
- the main buffer battery (BB);
- the reserve buffer battery; and
- the power supply test unit (BKIP).

The SB panels are oriented toward the Sun by means of the solar battery orientation system (SOSB). When a minimal voltage is reached, all consumers are automatically disconnected except for the duty systems, and a switch is made to the reserve BBO. After spacecraft dock, the orbital unit SEP charges the BB and supplies the transport spacecraft as long as they remain docked.

10. Life-support system (SOZh).—The SOZh is intended to provide conditions which will support the life of the crew; proper pressure and gas composition of the atmosphere, food and water, sanitary-hygienic conditions, and space-walk support.

The gas composition support system (SOGS) is intended to liberate oxygen (O_2) and absorb carbon dioxide (CO_2) and other impurities.

The system includes:

- chemical O_2 regenerators;
- chemical CO_2 absorbers;
- gas analyzers;
- harmful impurity filters (FVPs);
- dust filters (PFs); and
- gas stored in cylinders.

Additional regenerators, absorbers, FVPs, and gas are delivered by transport and cargo ships to replenish the supplies and allow continued operations of the system.

The system can maintain the parameters of the atmosphere within assigned limits ($CO_2 = 0.9$ mm mercury (Hg) $O_2 = 160$-280 mmHg, total gas pressure 760-960 mmHg) by manual connection and disconnection of regenerators and absorbers according to the readings of the gas analyzers.

The crew is supplied with water by regeneration of water from atmospheric moisture condensate and by reserves of stored water.

The water is stored in special containers.

Food is stored onboard the station as daily pacs in boxes. The food supply is supplemented by delivering it on transport and cargo spacecraft.

Sanitary-hygienic conditions are maintained onboard the spacecraft by means of a sanitary installation (ASU) [head—Tr.], shower, sets of linen, personal hygiene washcloths, and two lock chambers (ShK) with containers for waste ejection. Liquid wastes are collected in the sanitary device and ejected through the locks. Solid wastes (ASU, food, etc.) are collected in packets, then placed in special rigid containers designed for ejection through the locks.

Two spacesuits are used to allow two cosmonauts to perform space walks simultaneously. The transit section is used as a lock for this purpose.

11. **Medical Monitoring and Prophylaxis Equipment.**– This equipment is designed to allow regular medical monitoring of the cosmonauts' health and prevent harmful effects of spaceflight factors.

The system includes medical testing apparatus, an "Aelita" combined medical examination apparatus, a treadmill, bicycle ergometer, pneumatic vacuum suit, units for testing and indicating parameters of the crew's condition upon orbital insertion, and a pharmacy.

These devices are used for:

- regular medical testing, the information from which is transmitted to Earth through the telemetry channels;
- periodic medical examination with the "Aelita" apparatus, the data from which are recorded onboard the spacecraft and transmitted to Earth; and
- regular crew training (with a treadmill, bicycle ergometer, and pneumatic vacuum suit).

12. **Temperature Regulation System (STR).**—The STR is intended to support the proper temperature of structures, units, and apparatus of the orbital station and docked transport spacecraft, and to create comfortable temperature conditions within the habitation sections.

13. **Docking and Internal Transfer System (SSVP).**—The SSVP is intended to perform mechanical, electrical, and hydraulic docking of the orbital station with transport and cargo spacecraft, and to support internal transfer of cosmonauts from spacecraft into the station without passage through open space.

The docking unit is based on the rod (active portion) and cone (passive portion) principle.

The Soyuz T Transport Spacecraft

The Soyuz T spacecraft is an improved manned transport spacecraft for the delivery of the crew to Salyut orbital stations and return of the crew to Earth, as well as transportation of cargo.

The experience gained in the development of flights of Soviet spacecraft and stations was used extensively in designing the Soyuz T spacecraft.

The Soyuz T spacecraft is placed in orbit by a Soyuz booster rocket, which determined the size and mass of the new spacecraft. The well-proved Soyuz spacecraft, including the descent module, orbital (habitation) section, and instrument-equipment section, was used as the basis for arrangement of the new spacecraft.

However, the Soyuz T spacecraft differs in a number of details from the earlier craft, has improved characteristics and, particularly, increased effectiveness as a transportation vehicle for orbital space stations, plus improved reliability and crew safety.

The spacecraft is designed to carry up to three crew members in space suits. In addition to the special onboard systems, the spacesuits protect the crew in case of a loss of seal in the living spaces. If necessary, depending on the mission of each specific flight, the spacecraft crew may be reduced in number with no changes in spacecraft design. The free spaces are then used to carry special cargo containers, allowing, in combination with Progress spacecraft, the problem of delivering cargo to the station and returning cargo from the station to be solved.

Most of the onboard systems of the spacecraft were designed anew or modernized using systems design principles, new elements, and new production and testing technologies.

A new motion control system has been developed for the spacecraft, using an onboard digital computer. The system calculates motion parameters and automatically controls the spacecraft in the optimal mode with minimum fuel consumption, performs self-testing, and automatically switches if necessary to reserve programs and hardware, while outputting information to the crew via the onboard display.

The decisions implemented in the system assure higher accuracy, reliability, and flexibility of spacecraft control in both orbital flight and descent.

The crew can control the spacecraft manually not only in orbit but also during descent in the atmosphere.

The approach and correcting motor and docking and orientation micromotors operate with the same fuel components and have a common fuel storage and supply system, allowing more effective utilization of onboard fuel reserves. During flight the consumption of fuel is monitored by a special measurement system.

In order to improve reliability, the landing equipment system has been modernized, and the emergency crew rescue system, used as the spacecraft is placed in orbit, has been improved.

The radio systems of the spacecraft—such as the command-program radio link and radiometry and television systems—have been improved, and solar batteries have been included in the power supply system.

The design of the spacecraft provides for duplication of important mechanisms, sealing devices, separator units, etc.

The total volume of the living spaces aboard the Soyuz T is about 10 m^3.

The Progress Automatic Transport Spacecraft

The automatic transport spacecraft is intended for delivery of the following items to the Salyut piloted orbital station:

- scientific apparatus, photographic materials, crew life-support supplies, instruments, and units in need of replacement; and
- fuel components to recharge the combined motor installation of the orbital station.

In addition, it provides for the removal of wastes and units which have completed their operating life from the space station.

The automatic cargo transport spacecraft has a launch mass of 7 tonnes and consists of three main structural units:

- the cargo section (GO) with docking unit;
- the fuel component section (OKD); and
- the instrument and equipment section (PAO), consisting of the transit, instrument, and equipment sections.

The docking unit of the spacecraft is based on the docking unit of the Soyuz manned spacecraft and is designed for mechanical docking of the spacecraft with the station, to assure an airtight seal, and also to connect electrical lines and automatically connect and seal the main fuel supply lines. The crew passes through the docking unit into the cargo section of the spacecraft.

The cargo section of the spacecraft is intended to carry instruments, scientific apparatus, photographic materials, food, water, and life-support system equipment, including regeneration installations, all mounted on special frames and in containers. Throughout the flight, with the docking unit hatch sealed, conditions are maintained in the cargo section as required to preserve all of the instruments and food products being delivered to the space station. The volume of the cargo section is 6.6 m^3. The cargo section has an ordinary air atmosphere (760 mmHg). The temperature in the section is maintained between +3° and +30° C.

The cargo section is connected to the refueling component section. On the outer surface of the section are three antennas of the electronic approach system, two external television cameras (one aimed forward, the other toward the Earth), 103 light indices (used by the crew to monitor correct placement of the spacecraft during automatic approach and docking). Outside the section are the main lines which feed fuel components from the refueling section to the connections on the docking unit. The cargo section of the spacecraft can carry up to 1,300 kg of cargo to the orbital station.

The refueling component section structurally consists of two truncated conical shells. The section connects at one end to the cargo section, at the other end to the transit section and instrument and equipment section. At the outside of the section are two light indices which supplement the light index on the cargo section. This section is intended to carry tanks of fuel components for delivery to the orbital station, gas cylinders, and the equipment of the refueling system. The gas in the cylinders (nitrogen or air) is used to drive the fuel components during the refueling and also to fill the habitation compartments of the station if necessary.

The refueling system includes a system which tests the seal of the fuel lines, a blowing system, and sensors to monitor the temperature and pressure of the components and gas in the process of storage and refueling. During refueling, up to 1 tonne of fuel components can be transferred to the tanks of the combined motor installation of the station.

The refueling system is controlled by the crew of the orbital station, with radio signals from Earth controlling the cargo spacecraft end.

The instrument and equipment section is designed to carry all of the main service systems of the spacecraft supporting independent flight, approach and docking, flight as a part of the orbital station, and undocking.

The transit section of the instrument-equipment section is a framework which carries the fuel tanks, spherical containers, and fittings of the approach and orientation system motors. Outside the section are 10 approach and orientation motors of the system and the command radio link antenna.

The instrument and equipment sections are similar to the instrument and equipment sections of the Soyuz transport spacecraft in their design, purpose and apparatus, and equipment carried.

A Soyuz booster rocket is used to insert the transport cargo spacecraft into orbit.

After the cargo spacecraft separates from the booster rocket, structural elements carrying the antennas of the electronic approach system and radiotelemetry system, as well as the panel carrying the light indices, are deployed from the spacecraft.

Basic Information on the Soyuz Booster Rocket

The Soyuz booster rocket has three stages.

Stage I consists of four lateral units, each of which is 19 m long, 3 m in diameter; its motor has four chambers, two of which are steering chambers, developing a total thrust in a vacuum of 102 tonnes.

Stage II is the central unit, about 28 m in length, maximum 2.95 m in diameter, its motor has four chambers, all of which are steering chambers, developing a total thrust in a vacuum of 96 tonnes.

Stage III is a unit with a length of 8 m and a diameter of 2.6 m; its motor has four chambers (with steering nozzles), developing 30 tonnes of thrust in vacuum. The launch mass of the booster rocket with a Soyuz T spacecraft aboard is over 300 tonnes.

When the booster rocket is launched, the motors of the first and second stages are ignited simultaneously. The second stage continues to operate after the four lateral units [of the first stage] are jettisoned. The third stage is ignited after the second stage motor has completed operation. The booster rocket uses kerosene-oxygen fuel in all stages. The total length of the booster rocket with a Soyuz T spacecraft is 49 m. The maximum diameter at the stabilizers is 10.3 m.

Controlling the Flight of the Salyut Orbital Scientific Station

Organization of Flight Control

Flight control of the Salyut orbital scientific station, transport and cargo spacecraft is provided by:

- the flight control center near Moscow;
- a network of tracking stations;
- a system of modeling devices including a mathematical model of the station and a physical model of the spacecraft; and
- a communications system with Earth and satellite-information transmission channels.

Flight Control Center

The flight control center performs the following tasks:

- operational administration and coordination of the operation of the entire system;
- collection, processing, and display of telemetry, trajectory, and television information arriving from the station and from transport and cargo spacecraft; and
- interaction with the launch and search and rescue systems, trainers and modeling equipment, and various organizations participating in flight support.

The flight leader and flight control personnel are located at the center. The flight control center is equipped with a computer system; devices for collection, processing, and display of information; internal communications and television; remote-command output; communications with the crew; and transmission of telegraph messages to the Salyut station. The control center is in communications with the Moscow television technical center at Ostankino.

The flight control center has been significantly improved. It now has a second control room to control the flight of the transport and cargo spacecraft and a modernized computer system which now allows the problem of controlling several spacecraft simultaneously to be solved. At the same time the number of communications channels between the center and tracking stations has been increased to support simultaneous transmission of telephone, telemetry, and television information to the center from three spacecraft over surface channels and through Molniya communications satellites.

The modernized computer system of the center and the improved communications system allow transmission, processing, and display of information from all telemetry sensors of the Salyut station and from Soyuz spacecraft simultaneously for the control personnel.

The flight control personnel operating with the Salyut and Soyuz spacecraft systems are a carefully selected trained team consisting of specialists of various profiles. They include specialists on the flight program and flight control organization specialists, onboard systems developers, designers of the station and transport spacecraft, scientists, ballisticians, physicians, communications specialists, as well as specialists on the control and maintenance of the tracking stations, flight control central hardware, communications system hardware, plus representatives of scientific organizations of our country and other socialist countries.

Most of the control personnel are located at the flight control center—this is the chief operational flight control group. Some of the personnel are located at tracking stations and on ships of the U.S.S.R. Academy of Sciences, the Priroda state scientific research and production center, and the center for medical and biological research. The total number of personnel is about 100. Successful performance of the flight mission and completion of scientific research and crew safety depend on precise operations by every man.

The organizational structure of the flight control center personnel was developed by specialists with experience in the organization of manned spacecraft and station flight control, is recorded in special organizational documentation, and has been repeatedly tested in training exercises and in controlling the flights of previous stations and manned spacecraft.

The flight leader heads the control personnel.

Flight control is performed from two rooms: the main station flight control room and the transport and cargo spacecraft control room.

The personnel in the rooms work under the control of shift flight leaders.

Each room contains: the shift flight leader; specialists responsible for the main onboard systems; persons responsible for the operation of tracking stations; persons responsible for planning the flight program and for complete analysis of the operation of onboard systems; a cosmonaut operator in communication with the crew; representatives of the organizations which develop the station and spacecraft; a ballistics expert; a physician responsible for medical monitoring of the crew; the shift center leader; and specialists responsible for the main system at the center (communications, computer system, display systems, etc.).

All specialists work at positions with individual display and communications equipment.

The personnel work in four shifts. Shift changes occur during flight with no delay in flight operations.

Since the flight control center, tracking stations, and communications equipment are all the same for the station and the transport spacecraft, priority had to be assigned for their use. During orbital insertion, approach, and docking of the transport spacecraft with the station, the transport spacecraft control room has priority for use of equipment.

After docking and movement of the crew into the station, priority is transferred to the main control room. Priority transfer occurs at the moment the transfer hatches between the spacecraft and station are opened.

Organization of Work in Control Room

Control of the station or transport spacecraft is transferred to the control center from the launch complex immediately after separation of the last booster rocket stage.

Up to this point the personnel in the control rooms monitor the operation of onboard systems by telemetry, observe the crew by television, and listen to the conversations between the crew and the launch team.

A central screen shows the course of the booster rocket's flight over the entire insertion trajectory. After separation of the spacecraft from the booster the personnel in the control room monitor the opening of the antennas by telemetry, make contact with the crew, and begin testing onboard systems.

Work in the room is organized as follows: When the spacecraft enters the zone of visibility of ground tracking stations (the movement of the spacecraft is displayed on the central screen in the main hall) commands are transmitted to the spacecraft in accordance with the flight program. The personnel in the room monitor the transmission of commands and their reception by the spacecraft. The necessary onboard systems are switched on by commands from Earth or by the crew. The tracking stations begin to receive and transmit to the control center the telemetry, trajectory information, and television images received from the spacecraft. As the telemetry and trajectory data are received they are automatically processed by the control center's computers and transmitted to the display devices in the control room.

Telemetry information is analyzed in detail by systems specialists who generate conclusions concerning the status and operation of each onboard system for the responsible personnel.

Those responsible for individual systems are in communications with the support personnel outside the control center and can, if necessary, consult with them or obtain additional information on the operation of the systems.

In case of abnormal operation of spacecraft systems, the specialist responsible for overall analysis determines the effect of any system failures on the operation of individual systems, prepares suggestions for elimination of defects and correction of onboard system-operating modes, and then reports these suggestions to the shift flight leader.

The physician responsible for medical monitoring performs detailed analysis of biotelemetry data, estimating the condition of the crew and reporting it to the shift flight leader.

As trajectory information is processed and orbital parameters are determined, the ballistic data are automatically transmitted to the control room displays.

The communications operator carries on planned radio conversations with the crew. The person responsible for the tracking stations monitors their operation and, if there is any deviation from the planned program, informs the shift flight leader and takes steps to eliminate deviations.

The onboard computer specialist monitors operation of the computer and, if necessary, prepares changes to the computer program which are then transmitted to the spacecraft.

The center shift leader monitors the operation of all services at the center and, if there are deviations in any operations, informs the shift flight leader and takes steps to eliminate them.

The shift flight leader, considering all the information which he receives, makes decisions concerning the future flight program. If there are no deviations in the operation of onboard and ground-based systems, permission is given to perform operations in accordance with the planned program.

If it is necessary to correct the program, the correction is made by the person responsible for planning the program. Correcting actions may be undertaken during a session or in subsequent sessions. If necessary in order to identify failures and test correcting actions, a mathematical model of the station or the combined spacecraft physical model may be used. Decisions are implemented by transmitting instructions by radio from the flight control center to onboard systems or by verbal transmission of instructions to the crew.

Control Room Operation Support

In addition to the major specialists in the control room, there are also support groups at the center. The specialists in these groups are located in separate rooms equipped with positions similar to those in the control rooms. The main tasks of these personnel are to provide:

- support to personnel in the control room with calculations and information which can be used to make decisions concerning the flight program;
- consultation with control room specialists and assistance to them in analyzing the operation of onboard systems;
- assurance of implementation of decisions made by the shift flight leader;
- support for the operation of the technical equipment at the center; and
- prospective flight planning.

The personnel include the following specialists:

- specialists in onboard systems preparing and transmitting to the display devices the necessary additional information to control room specialists;
- specialists in operational planning of the flight program, to prepare, if necessary, changes to the flight program;
- specialists in advanced planning of the flight program (1 week);
- specialists in coordination of tracking station operations;
- specialists in communications which support communications of the center with the spacecraft and tracking stations;
- specialists in ballistics, included in the main ballistic center staff and performing the necessary ballistic calculations to determine the orbit, zones of visibility, entry and exit of the spacecraft from the shadow, maneuvers, as well as data necessary for scientific experiments;
- onboard computer specialists;
- representatives of the search and rescue system, constantly ready to go to work in case of an emergency return of the spacecraft;
- the medical monitoring group, which regularly analyzes biotelemetry and maintains communications with the flight medical support center;
- a group which plans the program for the crew's day off, prepares music transmissions for the crew, radio conversations between the crew and their families, and cultural and scientific activities; and
- to provide consultations to the flight leaders during experiments sponsored by representatives of another Socialist nation, the flight control center includes a consultation group of specialists representing the sponsoring nation.

Training of Control Personnel

Before starting to work at the center, control personnel undergo a training cycle. Training is performed using the mathematical model of the Salyut space station, the physical model of transport spacecraft, and training machines. Actual tracking stations and communications devices are used in these training exercises. The crew of the Soyuz T spacecraft participate in the training as well.

Training exercises are performed under conditions as close to those of real flight as possible. The flight program is developed in real time with interactions among individual groups of control personnel, the flight control center, and the tracking stations. Nonstandard situations which may develop on board and on ground are simulated. The most difficult flight stages are run through repeatedly.

The Baykonur Kosmodrom

The Baykonur Kosmodrom is a complex organization with many branches, a combination of unique devices, automatic systems, and engineering structures serviced by specialists of many sorts.

The Baykonur Kosmodrom is located in the Kazakh SSR in a semidesert area with a continental climate (hot, dry summer and cold, dry, windy winter). It was founded in 1955.

The reasons for selecting the location of the Kosmodrom were that it is remote from large populated areas, thus allowing safe rocket launches to be assured and separation zones (i.e., areas for the landing of returning spacecraft) to be set aside, and that many days in this area are cloudless.

Launches are performed from the Baykonur Kosmodrom in accordance with the national space research and utilization program of the U.S.S.R., in cooperation with other socialist nations in the "Interkosmos" program, and also in accordance with agreements for joint operations concluded with the United States, France, and other nations.

The world's first artificial Earth satellite was launched from the Baykonur Kosmodrom, the first cosmonaut Yu. A. Gagarin, and the first woman V. V. Tereshkova started from Baykonur; the Luna, Venera, Mars, and Zond automatic interplanetary stations were launched here, as were space stations and artificial Earth satellites of various types (Kosmos, Elektron, Polet), and the Molniya series of satellites used to relay television programs and to provide long-distance telephone and telegraph communications.

Manned Soyuz T spacecraft and Salyut orbital stations are regularly launched from the Baykonur Kosmodrom.

The Kosmodrom is used for assembly, testing, and launching of booster rockets with spacecraft, as well as for final prelaunch preparation of the cosmonauts.

The main component parts of the Kosmodrom are:

- the booster rocket assembly and testing building;
- the spacecraft assembly and testing building;
- the launch areas; and
- observation, command, and telemetry points.

The residential area of the Kosmodrom is located some tens of kilometers from the launch area and technical buildings. Here we find the cosmonaut training complex (classrooms for technical and scientific training of crews, the sports complex with swimming pool, laboratories to prepare the cosmonauts for flight, and the medical complex), as well as the institute, technical school, schools, club, stadium, television center, etc.

The Kosmodrom is connected to other points in the nation by air, highway, and rail. The territory of the Kosmodrom also has a well-developed network of highways and railroads.

The operations of assembly, testing, and joining of booster rockets and spacecraft are performed at the technical positions in the installation and testing buildings of the Kosmodrom, which are equipped with the necessary testing and measurement equipment and tools.

A number of launch and technical positions have been constructed at the Kosmodrom. One of the most important is the position from which three-stage booster rockets carrying the Vostok, Voskhod, Soyuz, and now Soyuz T spacecraft are launched.

The launch structure for this booster rocket includes a launch system with releasable supporting beams. The rocket is "suspended" in the launch system by the supporting units. The rocket system is delivered to the launch position from the assembly and testing building of this technical position, where it is assembled in the horizontal position.

The launch complex of the system, equipment, and engineering structures used to transport the rocket system to the launch position, set it in the launch structure, and perform prelaunch testing includes:

- the transporter and erector;
- the launch structures;
- the launch system (supporting frames and restraining devices; cables, hoses, and cable towers);
- the servicing devices (servicing frames and cabin); and
- the fuel and oxidizer supply systems.

The launch and other structures also contain: systems for filling and thermostatting fuel; a compressor station; compressed-gas receiver; fuel storage tank; a system to control both the preparation of the rocket for launch and the actual launch; the command point bunker, connected by communications lines to all operational services of the Kosmodrom; observation and command-measurement points; and the flight control center.

Preparation of the booster rocket for launch begins with transportation of its stages and sections of the spacecraft in special railroad cars from the manufacturing plants. The individual stages of the booster rocket are delivered to the spacecraft assembly building, where they are automatically tested, assembled, and prepared to be joined with the spacecraft. The spacecraft is assembled and tested in the spacecraft assembly building.

The ship is filled with fuel components and compressed gases at the filling station of the Kosmodrom, to which the spacecraft is delivered in a special railroad car. After it is filled and final operations are performed, the transit section and nose fairing are attached to the spacecraft. The assembled forward unit is then attached to the booster rocket, and the entire rocket-spacecraft system is tested.

This completes the work at the technical position, and the space system is delivered to the launch position on its transporter.

To install the rocket on the supporting beams of the launch system, the transporter raises the rocket to the vertical position by means of hydraulic jacks. During this time the supporting beams are shifted from an inclined position to their operating position and accept the weight of the rocket in its central (supporting) belt. The rocket is thus suspended over the gas-deflecting trough. Its tail portion is several meters below ground level. This helps to protect equipment on the ground from the powerful high-temperature jet of the motors.

The transporter, after placing the rocket on the supporting beams, lowers its boom to the horizontal position and rolls away the launch system. The servicing booms, cable, and hose towers are brought up to the rocket. As soon as they are in their operating position the process of azimuthal guidance of the rocket and placement of the rocket in the strictly vertical position is begun. All of these operations are performed by mechanisms on command of the remote control system. The air system which controls the temperature of the spacecraft is then started up. The essence of this operation is feeding of air beneath the fairing of the booster rocket at a rate such that the apparatus and fuel components remain within a defined temperature range. The air thermostatting system continues operating almost up to the moment of launch.

After the various lines are connected (fuel, drainage, pneumatic, electrical) to the rocket and spacecraft, the next operation begins—pressure-testing, i.e., checking the tightness of seal of all connection points with compressed air. Any pressure drop indicates a leak.

The testing and launch apparatus then begins prelaunch testing of the onboard systems and units of the rocket. All onboard systems are tested to determine if they are functioning properly and their initial conditions are correctly set; individual onboard and ground-based instruments are checked (without starting the standard programs or turning on the actuating organs); the television, communications, command radio link, onboard power supply, and other systems are tested. The results of prelaunch testing are displayed on all video-monitoring devices and recorded by the telemetry systems and multichannel recording machines. If all onboard system and unit parameters are normal, permission is given to begin fueling the booster and filling its compressed-air tanks.

The transfer of liquid oxygen into the booster is a special operation. The lines and tanks are first cooled; i.e., their temperature is artificially reduced to prevent the liquid oxygen from boiling off and to reduce the pressure in the booster's tanks and lines. For this purpose a small quantity of liquid oxygen is fed in from the storage container. As it evaporates, it cools the tanks and lines then passes through the safety and drainage valves in the gaseous state. After the tanks and lines are cooled, the pumps begin to operate. The level-monitoring system (SKU) assures precise measurement of fuel components.

Control of the filling process and monitoring of the transmission of instructions are performed remotely from the launch-pad command point.

At the same time as the booster rocket and the spacecraft are fueled, their systems, instruments, and units undergo final testing, adjustment, and simulated operation, and commands are transmitted to the memory unit of the onboard control system—it is set up to perform a definite program of orbital insertion.

Since liquid oxygen evaporates it must be topped off; i.e., additional liquid oxygen is pumped in to fill the tanks to the required level. The fuel components are then drained from the filling lines, after which the filling, drainage, and pneumatic lines are disconnected, and the correct vertical position and azimuthal guidance of the rocket are tested.

Two hours and thirty minutes before the launch the cosmonauts take their places in the spacecraft. The final prelaunch and launch operation program is started. The automatic system assures a launch at the precise time with an accuracy of a few hundredths-of-a-second. Final monitoring of all rocket system before the launch is performed by telemetry.

At minus 1 minute, when it becomes clear that all systems and units of the booster rocket and spacecraft are operating properly and the cosmonauts are ready for the launch, the operator places a switch in the "launch" position. The automatic final launch-operation program is started. Operations performed are displayed on the control panel. The fuel-and oxidizer-tank drainage lines are closed at this time. The cable and hose towers swing away from the rocket. The turbine pumps begin operating. The ignition is turned on. The pyrotechnic ignition devices create flames in the chambers of the first- and second-stage motors. The motors develop thrust, operating in the preliminary, intermediate, and then main operating modes. When the motor thrust exceeds the weight of the booster rocket it begins to rise and is freed from the clamps of the launch system support beams. At this instant a contact closes and the "launch" light begins to shine on the control panel. Information on the prelaunch preparation and insertion of the spacecraft into orbit is sent to the flight control center, where it is processed and displayed on the common and individual screens in the control rooms. Control of the spacecraft is transferred from the launch complex to the flight control center immediately after separation of the third stage of the booster rocket.

Command, Measurement, and Search and Rescue Systems

The flight of the Soyuz T spacecraft is controlled through the U.S.S.R. command and measurement complex, based on seven tracking stations in the Soviet Union—Dzhusaly, Yevpatoriya, Ussurisk, Ulan-Ude, Kolpashevo, Tbilisi, Petropavlovsk-Kamchatskiy, U.S.S.R. Academy of Sciences research vessels in the Atlantic and Pacific Oceans, and the USSR Academy of Sciences computer centers. These ground-based and ocean tracking stations are located so as to provide communications with the station and transport spacecraft in all orbits of the flight.

The longest continuous communications with the crew are provided for those orbits when the spacecraft dock, the crew move out for a space walk, or the spacecraft begins its return from orbit.

Command program information is transmitted from the control center to the tracking stations through automated telephone communications lines and is relayed from there to the orbital station. Telemetry and television information can also be recorded at the tracking stations for subsequent transmission to the flight control center.

The ground-based complex is a component part of the Salyut space station and Soyuz T spacecraft flight control loop. The control loop includes: the flight control center, ground-based and shipboard tracking stations, the ground and satellite communications system, and ballistic centers.

As it controls the flight, the ground-based control complex performs the following tasks:

- exchange of all types of information between the spacecraft and the flight control center;
- provision of two-way telephone and telegraph communications between the control center and the spacecraft crew;
- measurement of the parameters of the spacecraft's motion;
- organization of communications between elements of the ground-based control system and the flight control center; and
- operational administration and coordination of operation of tracking stations and other elements of the ground-based system.

The tracking stations in the process of a flight measure the parameters of the spacecraft's motion and receive telemetry and television information from the spacecraft. All decisions related to flight control are implemented through the tracking stations by conducting conversations with the crew and transmitting radio commands to the spacecraft.

There are about 20 telephone and telegraph communications channels between the center and a typical tracking station. Most tracking stations have wideband communications channels with the center. The tracking station is equipped with a computer which can perform about 50,000 operations per second. Elimination of telemetry redundancy from the flow of telemetry information is performed by specialized apparatus. The throughput capacity of the data transmission apparatus used over the telephone channels is 2,400 bps.

Shipboard command and measurement points receive and transmit to the center the complete flow of telemetry information from the spacecraft. Molniya communications satellites are used in the satellite communications system.

The tasks of the search and rescue complex include:

- search for and location of the returning spacecraft and cosmonauts,
- determination of the coordinates of their landing,
- evacuation of the cosmonauts and provision of medical aid,
- technical servicing of the spacecraft, and
- its removal from the landing area to its assigned point.

The men and equipment of the search and rescue complex are placed where the returning spacecraft will land. Helicopters and aircraft, observing the spacecraft visually and by radio, converge on their assigned locations along the landing track, using radio direction finding to approach the spacecraft and accompany it as it comes in for a landing, and maintain two-way communications with the crew.

The returning spacecraft land in a selected area of the Soviet Union. The descent apparatus is designed to land on dry land; the apparatus has special systems assuring safety of the cosmonauts should it land in water.

In the landing area the cosmonauts are met by a specially trained search group. This group includes technical specialists and physicians. The search group is provided with everything necessary to reach the landing point rapidly and to provide any needed assistance to the cosmonauts.

The search aircraft carry parachute personnel including physicians and rescue specialists who if necessary parachute to the spacecraft after it lands. Search and rescue equipment includes aircraft and helicopters, ships and all-terrain vehicles. The technical specialists and physicians included in the search group are well-trained parachute jumpers and scuba divers. The physicians of the group have available the necessary medical equipment and medications, adapted for use under any weather conditions.

After landing, the cosmonauts open the hatches of the spacecraft and prepare containers of scientific apparatus and photographic film for transportation. If necessary they can use the reserve stores onboard the spacecraft, including warm clothing, swimsuits, signaling and radio communications devices, extra water, and other necessary products. After landing and leaving the spacecraft, the cosmonauts take off their spacesuits and put on flight clothing. The containers of scientific apparatus and film are turned over to the specialists in the search group. The cosmonauts undergo post-flight physical examination at the landing point.

If the spacecraft lands in water, the cosmonauts remove their spacesuits, don special equipment, prepare to use their flotation devices, and maintain contact by radio with the search service. The search group which arrives at the landing zone helps the cosmonauts to leave the spacecraft.

The search process, location of the spacecraft, and evacuation of the cosmonauts from the spacecraft and from the landing zone are all reported from the area in which the search and rescue complex operates to the flight control center.

The Yuriy Gagarin Cosmonaut Training Center

The Yuriy Gagarin Cosmonaut Training Center (TSPK) was created in 1960 and is located outside Moscow, in Zvezdnyy Gorodok [Star Village].

The cosmonaut training center is an institution provided with modern equipment and manned by qualified specialists, capable of training crews for space and expeditions in accordance with the increasing demands of the time.

The specialists at the Center have accumulated great experience in educational, scientific, and indoctrination work. They take part in studies of the prospects of using manned spacecraft, and contribute to the improvement of spacecraft and their equipment and to the planning of future flights.

The structure of the TSPK, the mission of its main subunits, and [the composition of its] professional staff of specialists are determined by the tasks which it performs in preparing and supporting space flight.

In 1968 the Center was named in honor of Yuriy Gagarin.

In 1971, for its great services in the preparation of crews for spaceflight, its participation in the mastery of space, and in connection with the 10th anniversary of the world's first manned space flight, the center was awarded the Order of Lenin.

During the operation of the TSPK (up to June 1 1982) 49 manned spacecraft crews were trained, including: 6 for the Vostok spacecraft, 2 for the Voskhod spacecraft, 37 for the Soyuz spacecraft, 4 for the Soyuz T spacecraft. Sixty cosmonauts had been in space, including 10 three times (Vladimir Shatalov, Aleksey Yeliseyev, Valeriy Bykovskiy, Petr Klimuk, Nikolay Rukavikhnikov, Valeriy Kubasov, Valeriy Ryumin, Viktor Gorbatko, Oleg Makarov, Vladimir Kovalenok), and 15 twice, as well as 9 cosmonauts who were citizens of other Socialist nations: Vladimir Remek (CSSR), Miroslav Germashevskiy (Poland), Zigmund Jen (GDR), Georgiy Ivanov (Bulgaria), Vertalan Farkash (Hungary), Fam Tuan (Viet Nam), A. Tamayo Mendes (Cuba), Zhugderdemidiyn Gurragcha (Mongolia), and Dumitru Prunariu (Roumania).

In 1980 the cosmonaut training center celebrated its 20th anniversary.

Appendix B

Soviet Space Stations: Achievements, Trends, and Outlook

Geoffrey E. Perry, MBE
November 1982

> My mathematical conclusions, based on scientific data verified many times over, show that with such devices it is possible to ascend into the expanse of the heavens, and perhaps to found a settlement beyond the limits of the Earth's atmosphere. . . . People will take advantage of this to resettle not only all over the face of the Earth but all over the face of the Universe. . . .
>
> —K. E. Tsiolkovsky 1903

It is a widely held belief that the Soviet space program deliberately follows the paths described in the early years of the century by Konstantin Tsiolkovsky.[1] Be that as it may, it is certainly possible to find close parallels between Tsiolkovsky's writing and the course of events, but more likely these parallels result because modern engineers have arrived at similar solutions to the same problems rather than because of slavish obedience or preconceived notions.

Smolders[2] holds that the concept of space stations forms the nucleus of Tsiolkovsky's vision of space travel. Tsiolkovsky considered the construction of a permanent base in space to be the first important step towards a landing on the Moon and exploration of the planets. A space station concept attributed to Tsiolkovsky depicting a closed ecological system and garden, laboratories, living quarters, and a docking port with an airlock has been reproduced in official Soviet publications. Illustrations of other space stations appearing on commemorative stamps owe more to the designs of Shternfel'd and others which are to be found in a handbook produced by the staff of the Battelle Memorial Institute.[3] A 1964 Soviet Defense Ministry book on *Manned Space Stations* listed the building of a larger manned space station, with a crew of 30 to 50, in the 1972-75 period, as the third of five further stages in space conquest.[4] To date, the maximum number to man a complex at any one time has been five for the Apollo-Soyuz mission and two visits to Salyut 7.[5]

After the "troika" mission of Soyuz 6, 7, and 8 in 1969, Leonid Brezhnev said, "Soviet science views orbital stations with interchangeable crews as man's major highway into space. . . . Major scientific laboratories will appear for conducting research in space technology and biology, medicine and geophysics, astronomy and astrophysics."[6]

According to Feoktistov and Markov, direct work on Salyut space stations began in 1969.[7] To reduce cost and to shorten the construction time as many units and separate systems as possible were used from Soyuz, Zond, and other tried and tested designs. Most of these needed modification as they did not provide the required service-life, and basic systems, such as the heat supply, were built from scratch. The intention of using the manned mode opened up the possibility of in-orbit repair and replacement of defective subsystems, thereby increasing the reliability and life of the station.

A study of Soviet space station philosophy demands consideration of Salyut, Soyuz, and Progress spacecraft as components of an orbital complex. The Soyuz acts as a manned transport craft between Earth and the orbiting space station, remaining docked with the station whilst the crew is on board, in the same manner as the Apollo was used for three missions to Skylab and, presumably, the Shuttle orbiters will be used with any future National Aeronautics and Space Administration (NASA) space station. Progress, a Soyuz derivative, has an unmanned role as an expendable cargo vehicle.

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[1] V. Rich, *Nature* 250 (London: July 19, 1974), p. 177.

[2] PL, "Soviets in Space" (Guildford: Lutterworth Press, 1973), p. 34.

[3] G. E. Wukelic (ed.), *Handbook of Soviet Space-Science Research*, Gordon and Breach, New York, 1968. pp. 473-486.

[4] I. N. Bubnov and L. N. Kaminin, "Manned Space Stations," *Voyennoye Izdatel'- stvo Ministerstva Oborony SSSR* (Moscow: 1964) and quoted in M. Stoiko, "Soviet Rocketry," p. 209.

[5] *Apollo*, Thomas Stafford, Donald Slayton, and Vance Brand. *Soyuz*, Aleksey Leonov and Valeriy Kubasov. Docked 1309 Z, July 17, 1975. First undocking 1203 Z, July 19. 37 min. undocked. Second docking 1240 Z, July 19. Final undocking 1526 Z, July 19, 50 hr. 17 min. total, 49 hr. 40 min. net. *Soyuz-T 5*, Anatoliy Berezovoi and Valentin Lebedev. *Soyuz-T 6*, Vladimir Dzhanibekov, Aleksandr Ivanchenkov, and Jean-Loup Chretien. Docked 1746 Z, June 25, 1982. Undocked 1101 Z, July 2, 161 hr. 15 min. total. *Soyuz-T 7*, Leonid Popov, Aleksandr Serebrov, and Svetlana Savitskaya. Docked 1832, Aug. 20, 1983. Undocked 1145 Z, Aug. 27, 161 hr. 13 min. total.

[6] Brezhnev's statement quoted by A. S. Yeliseyev at press conference following end of manned phase of the Salyut 6 mission, reported in *Izvestiya*, July 14, 1981, p. 2, reproduced in JPRS 79319, Space #13, Oct. 28, 1981, p. 4.

[7] K. P. Feoktistov and M. M. Markov, "Evolution of 'Salyut' Orbital Stations," Zemlya i Vselbnnya, 5, September-October 1981, pp. 10-17, reproduced in JPRS 80424, Space No. 15, Mar. 29, 1982, p. 1.

Although certain events in the history of the Soviet space program have been spectacular at the time, it must be realized that they are not instant technological breakthroughs but rather are the results of careful planning and cautious steps towards the desired goals. The docking of the Soyuz 4 and 5 spacecraft in 1969, claimed as establishing "the world's first orbital space station,"[8] should be seen as the first docking of two manned Soviet spacecraft following two successful automatic dockings of unmanned satellites in the Cosmos series.[9] The clue to the intended function of the Soyuz was to be found in the name "Union," although a characteristic element of ambiguity was also present. The EVA transfer of cosmonauts between the two spacecraft demonstrates the step-by-step approach and unsophisticated design philosophy.[10] Internal crew transfer was not accomplished until Soyuz 11 docked with Salyut 1 more than 2 years later.

The Soyuz T (T = transport) currently in use with the Salyut 7 space station has evolved through several variants. Tested unmanned in the Cosmos series, Soyuz 1 malfunctioned and killed cosmonaut Komarov during the return to Earth when the parachute failed to deploy correctly.[11] This resulted in an 18-month period of redesign before testing recommenced with the unmanned rendezvous and docking of Cosmos 186 and 188. As in Voskhod, crews flew without spacesuits and a three-man capacity was demonstrated with Soyuz 5 although, for the Soyuz 9 recordbreaking 18-day flight, the crew was reduced to two to permit sufficient consumables to be carried. The loss of the crew of Soyuz 11 returning from the 24-day mission to Salyut 1 necessitated a further period of redesign.[12] To accommodate a life-support system and a spacesuited crew, one of the seats was removed and Soyuz flew as a two-man spacecraft for the remainder of its life, ending with Soyuz 40 in 1981.[13]

Prior to this, unmanned flights in the Cosmos series, having characteristics similar to those of manned missions, pointed to the development of a new manned spacecraft.[14] It was mildly disappointing when, on its first flight to the Salyut 6 space station at the end of 1979, it was named Soyuz T and then shown in photographs to have the same external shape and dimensions of the old Soyuz.[15] Internal redesign has restored the three-man capacity,[16] whilst permitting the use of spacesuits at critical phases of the mission, and an on-board computer has enhanced its performance. Whereas the early Soyuz spacecraft were stated to have a 30-day capability, Soyuz T 5 functioned in orbit for 106 days, during which it was docked with Salyut 7 for 103 days.[17]

A major disadvantage of using the Soyuz appears to be the tight constraint imposed by lighting conditions during recovery. Information released at the time of the Apollo-Soyuz Test Project (ASTP) revealed that landings should occur at least 1 hour before local sunset and that a minimum of 8 minutes should elapse between eclipse-exit and retrofire. Graphical analyses by Christy[18] and Clark[19] show that the 31 revolutions repeating pattern of ground tracks employed for the Salyuts 6 and 7 lead to landing "windows" at intervals of approximately 2 months. Moreover, the duration of these windows varies from only 7 to 10 days depending on the time of year. These windows, in turn, impose constraints on mission durations. The 8-day Intercosmos missions, for example, were launched immediately prior to the opening of a landing window so that, if the need to abort prematurely should arise, as with the Bulgarian mission, the constraints could be obeyed on the third day.[20] To date, Soyuz T spacecraft have also obeyed these constraints and have yet to demonstrate the capability to make normal landings at any time of the day or night. If this practice is followed for Berezovoi and Lebedev, then the next window opening around the end of the year would prolong their mission to something in excess of 230 days.[21] The constraints could be obeyed in an emergency at other times of the year by moving the recovery zone from the Kazakhstan region. Cosmonauts have been depicted training for recovery from landings in water should such landings prove to be necessary.[22]

Up to a few years ago, the orbital module remained attached to the command module until after retrofire.

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[8] Phrase used in a question by the *Tass* correspondent at Cosmonauts' press conference in Moscow, Jan. 24, 1969, reported in SU/2984/C/4.

[9] *Cosmos 186* launched Oct. 28, 1967. *Cosmos 188* launched Oct. 30: First orbit rendezvous and docking at 0920 Z, Oct. 30. Undocked at 1250 Z; 3 hr. 30 min. total time docked. *Cosmos 212* launched Apr. 14, 1968. *Cosmos 213* launched Apr. 15: First orbit rendezvous and docking at 1021 Z, Apr. 15. Undocked at 1411 Z; 3 hr. 50 min. total time docked.

[10] *Soyuz 4*, Vladimir Shatalov, launched Jan. 14, 1969. *Soyuz 5*, Boris Volynov, Yeugeniy Khrunov, and Aleksey Yeliseyev, launched Jan. 15: 18th orbit rendezvous and docking at 0820 Z, Jan. 16. Undocked at 1255 Z; 4 hr. 35 min. total time docked.

[11] *Soyuz 1* with Vladimir Komarov crashed Apr. 24, 1967.

[12] Soyuz 11 landed on June 29, 1971; its three crewmen, Georgiy Dobrovolskiy, Vladislav Volkov, and Viktor Patsayev, perished.

[13] *Soyuz 40* landed May 22, 1981.

[14] *Cosmos 1001* launched Apr. 4, 1978, recovered after 11 days; *Cosmos 1074* launched Jan. 31, 1979, recovered after 60 days.

[15] *Soyuz-T* launched Dec. 16, 1979.

[16] *Soyuz-T 3*, Leonid Kizim, Oleg Makarov and Gennadiy Strekalov launched Nov. 27, 1980.

[17] *Soyuz-T 5* landed Aug. 27, 1982.

[18] R. D. Christy, "Safety Practices for Soyuz Recoveries," *Spaceflight* 23, 1981, pp. 321-322.

[19] P. S. Clark, "Soyuz Missions to Salyut Stations," *Spaceflight* 21, 1979, pp. 259-263.

[20] *Soyuz 33*, Nikolay Rukavishnikov and Georgiy Ivanov, Apr. 10-12, 1979.

[21] *Soyuz-T 7* landed in poor conditions at night, Dec. 10, 1982, 211 days 9 hr. 5 min. record duration.

[22] *Spaceflight* 20, 1978, p. 305 shows Aleksey Gubarev and Vladimir Remek practicing for Soyuz 28.

Latterly, it has been jettisoned prior to retrofire.[23] The orbital module, filled with bulky, used equipment, burns in the atmosphere on reentry and provides a means for disposing of unwanted material as an alternative to the regular use of the airlocks. The unloaded Progress performs a similar function but is deorbited over the Pacific rather than being left to decay naturally. The crew capacity of the Soyuz T is limited to three by the use of the A-2 vehicle for its launch. This booster, using the same first stage as that used to launch the first Sputnik 25 years ago, is the only Soviet booster to be man-rated to date. The larger D vehicle now appears to be totally reliable and could possibly be man-rated at some future date for launching spacecraft with larger crew complements, and some Western observers speculate that the mysterious dual payload launches at 51.6° inclination were reentry tests of reusable winged spacecraft.[24] The Cosmos 1374 mission of summer 1982 has been claimed to have been a reentry test of a scale model winged spacecraft, launched by the intermediate capacity C vehicle; the Royal Australian Air Force released pictures of the follow-on Cosmos 1445 spacecraft being recovered from the Indian Ocean.[25] Nevertheless it is not unreasonable to suppose that research and development work leading to a reusable manned spacecraft to service a permanently manned space station is in hand.

The unmanned Progress craft is something more than an interim measure to provide space-station crews with fresh supplies. The Soviets have mastered the technique for resupplying their Salyut stations with propellant and potable water, a feat unmatched in the Skylab missions and, as yet, unnecessary for the space Shuttle. Moreover, the residual propellant of the Progress engine has been used to maneuver the Soyuz-Salyut-Progress orbital complex in the manner of a primitive space tug.[26]

The altitudes selected for the Salyut missions below the Van Allen radiation belts[27] are not the most economical in terms of propellant usage. The relatively high air-drag, particularly in the case of the "military" Salyuts 3 and 5,[28] made great demands on stored propellants to maintain the orbit throughout the duration of the missions. Choice of a greater altitude to minimize propellant consumption exacts a penalty in terms of surface resolution for Earth observation programs. As space stations increase in physical size and complexity the drag problem will attain an even greater significance.

The small interior volume of the Salyut stations, which have an effective floor-area of 16 square meters[29] in the working compartment, must lead to cramped conditions, especially at times when the cosmonauts are joined by visiting crews. A first step towards increasing the interior volume came with the docking of Cosmos 1267, a "prototype space module,"[30] with Salyut 6. Although this docked complex was never manned, it was claimed[31] that future stations could be enlarged by docking with modules dedicated to different disciplines including crew rest and relaxation. The Cosmos 1267 engine was used to maintain the Salyut 6 orbit[32] and eventually to deorbit the docked complex at the close of the joint mission.[33] Cosmos 1267 and its predecessor, Cosmos 929, were both reported to have returned part of their structure to Earth after a period of some 30 days.[34] Salyuts 3 and 5 also returned capsules during the unmanned phases of their missions, and thus an unmanned return capability already can be seen to exist.[35]

Another disadvantage of the current Salyut program is the lack of near-continuous communication with ground stations. For long periods in each orbit the crew is out of touch with ground control. In the initial stage of Soviet manned spaceflight this disadvantage was partially overcome by the use of shortwave frequencies for voice communication as well as the long-range housekeeping telemetry still in use today. Later, merchant ships were converted to provide communication links through Molniya satellites,[36] and purpose-built vessels have since modernized the space support fleet maintained by the U.S.S.R. Academy of Sciences.[37]

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[23] Orbital module of first Soyuz-T discarded 25 March 1980, catalogued by RAE as 79-103D but as 77-97BR by NORAD.

[24] *Cosmos 881-82*, Dec. 15, 1976; *Cosmos 997-998*, Mar. 29, 1978; *Cosmos 1100-1101*, May 22, 1979; and T. Williams, "Soviet Re-entry Tests: A Winged Vehicle?" *Spaceflight* 22, 1980, pp. 213-214.

[25] *Aviation Week & Space Technology* 116, June 14, 1982, p. 18; and *Cosmos 1374*, June 3, 1982. (Pictures of the 1983 flight of Cosmos 1445, a similar spacecraft, taken by the Royal Australian Air Force have been published by the world's media.)

[26] ". . . during the joint flight the engines of Progress 15 had been used to make two adjustments of the trajectory of the orbital complex." (*Tass* in Russian for abroad, 1436 GMT, Oct. 14, 1982, reported in SU/7163/D/3.

[27] Explorer 1 discovered radiation belt at 950 km.

[28] *Salyut 3* 256-292 km. Salyut 5 214-257 km.

[29] Yu Semenov and L. Gorshkov, " 'Salyut 6' Orbital Station: Home, Laboratory, Vehicle," *Nauka i Zhizn'*, April 1981, pp. 43-53, 125, reproduced in JPRS 78779, Space #12, Aug. 19, 1981, p. 7.

[30] Cosmos 1267 docked with Salyut 6 at 0752 GMT, June 19, 1981. *Moscow Home Service*, 0930 GMT, June 19, 1981, reported in SU/6755/D/1.

[31] Interview with Konstantin Feoktistov, UPI, 1248 GMT, June 24, 1981; and interview with Konstantin Feoktistov, *Tass*, Russian for abroad, 0508 GMT, June 24, 1981, reported in SU/6770/D/1.

[32] *Moscow Home Service*, 1400 GMT, July 1, 1981, reported in SU/6770/D/1.

[33] *Tass*, Russian for abroad, 1057 GMT, July 29, 1982, reported in SU/7095/D/1.

[34] "Part of New Soviet Space Station Deorbited and Recovered," *Defense Daily*, May 29, 1981, p. 153. (Cosmos 1267 capsule returned May 24, 1981.)

[35] Salyut 3 returned capsule on Sept. 23, 1974. *Tass*, Russian for abroad, 1405 GMT, Sept. 26, 1974, reported in SU/4715/C/1 and Salyut 5 returned capsule on Feb. 26, 1977. *Tass* in Russian, 1502 GMT, Mar. 2, 1977, reported in SU/5458/C/1.

[36] *Tass* in English, 0900 GMT, Oct. 18, 1969, reported in SU/3207/C/2.

[37] G. Bezborodov and A. M. Zhakov, "Suda Kosmicheskoy Sluzhby," *Izdatel'stvo "Sudostroyeniye,"* (Leningrad: 1980), reproduced in JPRS L/9862, Space FOUO 3/81, pp. 1-21.

Details of an Eastern Satellite Data Relay Network (ESDRN) lodged with the International Frequency Registration Board in 1981[38] show that the Soviet Union intends to operate a system employing frequencies in the Ku-band[39] similar to the American TDRSS for communicating with Salyut stations and other spacecraft in low-Earth orbit, commencing no sooner than December 1985.

Following the end of the manned phase of the Salyut 6 mission in 1980, articles appeared in the daily and technical press detailing the achievements and outlining future needs.[40] Isvestiya stressed that those achievements were not only in the great reliability and longevity in space of the onboard systems and equipment but also in the vast amount of experimental work aimed at finding solutions for fundamental scientific problems and practical requirements on Earth today. The requirements of 22 of the Ministries and Departments of the U.S.S.R. were considered.

More than 1,600 experiments were said to have been performed involving some 150 items, many of which were repeated at least once.[41] Of these, 60 were astrophysical, 200 on the production of materials of exceptionally high purity, and 900 in medicine and biology. Many of the latter were in cooperation with other countries as part of the Intercosmos program. The superpure materials ranged from the homogenous alloys and semiconductor materials, produced in the Kristall, Splav, and Isparitel furnaces and ovens,[42] to vaccines produced by electrophoresis.[43] Much time was devoted to the observation of the Earth from space. Some 13,000 photographs were obtained using the Kate-140 topographical and MKF-6M multispectral cameras.[44] As a result, a supply of freshwater was located in the Kyzyl-Kum desert and large-scale geological features coinciding with mineral deposits and possible oil-bearing regions were identified.[45] It was stated that photographs of an area covering 1 million km² could be recorded on film in 10 minutes, equivalent to the result of several years' aerial photography.[46] (Salyut 4 was reported to have returned photographs of 4.5 million km² of the U.S.S.R.)[47] In addition to radioastronomy, experiments with the KRT-10 in 1979,[48] astronomical observations of active areas of the Sun's surface and other X-ray sources were made and infrared radiation from the planets and stars was recorded using the cryogenically cooled 1.5-meter diameter BST-1M telescope.[49] For these observations an orientation accuracy of a few arc seconds was maintained,[50] and some Western commentators have seen military implications related to the pointing of directed-energy weapons in this context.[51] Undoubtedly, there is a large area in which military and scientific experimental programs overlap each other.

Experience has shown that it is possible for crews to work in space for long periods at a time so long as they follow a regular exercise regime[52] to counteract the effects of prolonged weightlessness. Equally important is sustaining the psychological well-being of the crew.[53] To this end consideration has been given to the interior decoration of the station.[54] It was found that working to a normal Earth time schedule was beneficial both to the cosmonauts and the ground-support teams. Regular rest days at weekends are used for housekeeping and relaxation. The introduction of a two-way television link[55] enabling the cosmonauts to see their families whilst talking to them at the weekends was a great morale-booster as were the visits from short-term crews. However, the strain began to tell on the Salyut 7 cosmonauts who set the record of 211 days in space, and their working day was reduced from 16 to 12 hours.[56]

And what of the future? Steps must be taken to overcome the disadvantages of the current program mentioned above. More efficient transport crafts are needed. A Soyuz can deliver only 50 kg of supplies in addition to its crew, and Progress is limited to 2,300 kg.[57] Although Progress transports delivered more than 20 tonnes of supplies to Salyut 6 in 12 visits, the greater part of the cargo comprised life-support system supplies and units, fuel and replacements for onboard systems.[58] A man requires more than 10 kg of replacement life-support system elements every day,[59] and there is an obvious need to change over to a new life-support system operating on a closed cycle, thereby eliminating the need to deliver water and atmospheric purification supplies. (A water-regeneration system did not produce in excess of 500 liters of potable water on Salyut 6.)[60] A reduction in the amount of fuel necessary for station orientation could be effected by the adoption of an electromechanical orientation system.[61] (Trials of this type of system were conducted on Salyut 3 and must be presumed to have been less than satisfactory since this principle has yet to be adopted operationally.)

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[38] Special Section No. SPA-AA/343/1484 annexed to IFRB Circular No. 1484, Sept. 1, 1981.

[39] 10.82, 11.32, 13.7 and 13.52 GHz downlink; 14.62 and 15.05 GHz uplink.

[40] Feoktistov and Markov, idem.; and Semenov and Gorshkov, idem.; and "Looking to Orbits of the Future," *Isvestiya*, July 14, 1981, p. 2, reproduced in JPRS 79319, Space #13, Oct. 28, 1981, pp. 3-6; and K. Feoktistov, "To Future Orbits," *Pravda*, June 9, 1981, p. 3, reproduced in JPRS 79319, Space #13, Oct. 28, 1981, pp. 45-46.

[41] Ibid., p. 46.

[42] Semenov and Gorshkov, idem. p. 9.

[43] Feoktistov and Markov, idem., p. 11.

[44] Feoktistov, idem., p. 46.

[45] Feoktistov and Markov, idem., p. 4.

[46] A. P. Aleksandrov, *Isvestiya*, July 14, 1981, p. 2, reproduced in JPRS 79319, Space #13, Oct. 28, 1981, p. 3.

[47] Feoktistov and Markov, idem., p. 4.

[48] N. S. Kardashev, A. I. Savin, M. B. Zakson, A. G. Sokolov, and K. P. Feoktistov, "The First Radio Telescope in Space," *Zemlya i Vselennaya*, No. 4, July-August 1980, pp. 2-9, reproduced in JPRS 76578, Space #7, Oct. 8, 1980, pp. 1-15.

[49] Feoktistov and Markov, idem., p. 6.

[50] Feoktistov, idem., p. 46.

[51] "Washington Round Up," *Aviation Week & Space Technology* 117, No. 17, Oct. 25, 1982, p. 15.

[52] Semenov and Gorshkov, idem., p. 15.

[53] N. Novikov, "An Extended Expedition," *Sovetskiy Voin*, No. 8, 1981, pp. 29-29, reproduced in JPRS 78779, Space #12, Aug. 19, 1981, pp. 26-29.

[54] Ibid., p. 8.

[55] Idem., p. 28.

[56] *Moscow World Service* in English, 1000 GMT, Oct. 27, 1982, reported in SU/7182/D/1.

[57] Novikov, idem., p. 27.

[58] Feoktistov and Markov, idem., p. 10.

[59] Ibid., p. 9.

The introduction of a new onboard computer system for Salyut 7 has relieved the crew of much routine work connected with the operation of the station.[62] This is markedly noticeable in communication sessions with ground control. On previous missions much time was spent in calling "Zaria," the ground control, in order to confirm that two-way contact had been established. Today, the computer switches on the transmitter when the stations rises above the radio horizon of the ground station, and the cosmonauts speak from wherever they chance to be in the station at the time. Feoktistov, commenting on the introduction of computer and microprocessor technology, has cautioned that enthusiasm for automation can lead to extraordinary complexity and, consequently, a reduction of equipment reliability.[63]

The elimination of the need to mothball the station between periods of occupancy by long-term crews would be a logical step in the steady evolution of Salyut operations. A further improvement would be the provision of facilities for receiving water and propellant from Progress transports at either of the two docking ports. This would eliminate the transportation and redocking which has hitherto been necessary to relocate the Soyuz at the forward docking port in order to accommodate a Progress at the aft port. Such redesign may also encompass provision of nonaxial docking ports although destruction of axial symmetry could introduce problems in maneuvering and altitude control.

In the distant future one might expect the Soviets to take steps to establish a permanent space station in geosynchronous orbit[64] for the collection of solar energy, its conversion to electrical energy, and transmission to Earth by microwaves, but these possibilities introduce difficulties several orders of magnitude greater than those solved to date.

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[60] Feoktistov and Markov, idem., pp. 10-11.

[61] Idem., p. 11.

[62] *Moscow Home Service*, 1800 GMT, May 21, 1982, reported in SU/7034/D/2; and *Moscow Home Service*, 0200 GMT, May 23, 1982, reported in SU/7048/D/2; and *Isvestiya*, July 16, 1982, reported in SU/7122/D/3.

[63] Feoktistov and Markov, idem., p. 10.

[64] Idem., p. 11.

Appendix C

OTA Workshop on Soviet Space Station Activities

List of Outside Participants

Craig Covault
Aviation Week & Space Technology

Leonard David
National Space Institute

Merton Davies
The Rand Corp.

Ed Ezell
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John R. Hilliard
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Nicholas Johnson
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Saunders Kramer
Department of Energy

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Biotechnology, Inc.

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NASA Headquarters

Marcia S. Smith
Congressional Research Service

Additional Reviewers

Hubert Bortzmeyer
Christopher H. Dodge
Russell Drew
Paul Hanle
Thomas Karas
Charles Kelly
Gordon Law
John Logsdon
George Mueller
Joseph Rowe
Carl Sagan
Charles P. Vick
Ray A. Williamson
Simon P. Worden

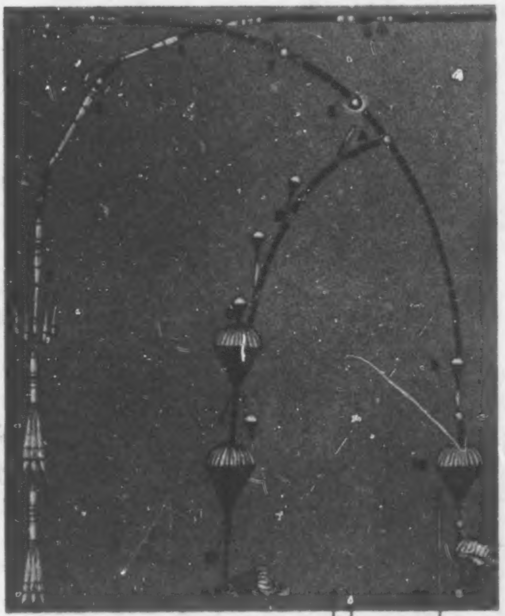
Vostok Flight Profile

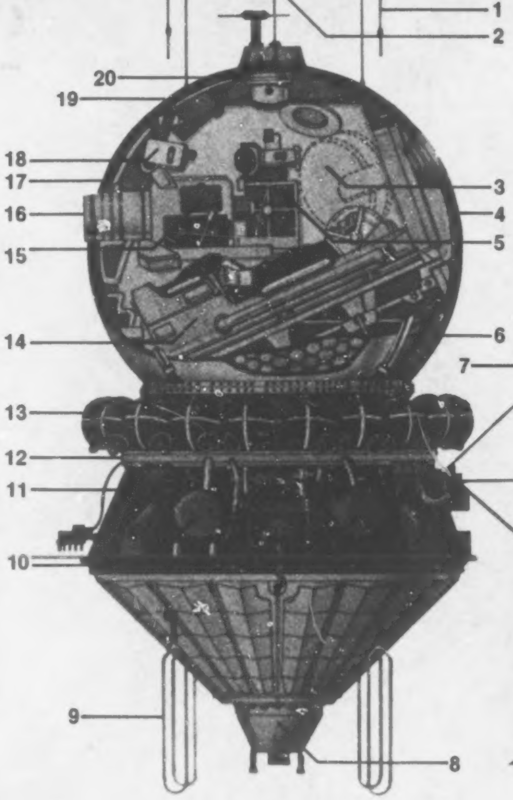
1 Lift-off, of A-1.
2 Boosters jettison.
3 Central core continues; nose shroud jettisons.
4 Central core separates; final stage inserts spacecraft into orbit.
5 Final stage separates.
6 Orientation for retro-fire.
7 Re-entry capsule and electronics pack separates from equipment module.
8 Re-entry heating.
9 Drogue parachute ejects at 13,124ft (4,000m).
10 Drogue parachute jettisons and main parachute opens.
11 Capsule lands. (Only Gagarin chose to land in the capsule.)
A Escape hatch jettisons at 22,967ft (7,000m). Cosmonaut emerges on ejection seat.
B Ejection seat discarded at 13,124ft (4,000m).
C Cosmonaut's parachute opens.
D Dropping in.
E Lands.

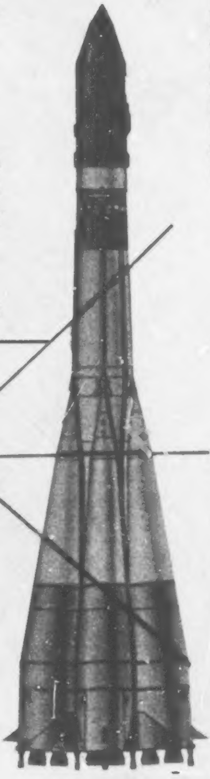
Vostok 1

1 Command control antenna.
2 Communications antenna.
3 Housing for umbilical connectors.
4 Escape hatch.
5 Food locker.
6 Tensioning bands.
7 Whip antennas.
8 Retro-rocket.
9 Communications antenna.
10 Access hatch.
11 Equipment module with basic systems.
12 Electrical harness.
13 Oxygen and nitrogen, pressure bottles (16) for life-support system.
14 Ejection seat.
15 Radio antenna.
16 Porthole with "Vzor" optical orientation device.
17 Technological hatch.
18 TV camera.
19 Ablative heat-shield.
20 Electronics pack.

The craft consisted of two basic modules, the 90•5 in (230cm) diameter re-entry capsule and the equipment module. The craft made use of an automatic control system which the cosmonaut could override. With his right hand he could orient the craft by means of a hand controller. With his left hand he could operate the abort switch which blew the capsule's escape hatch and operated the ejection seat. A cut-out in the nose shroud of the launch vehicle allowed the cosmonaut to escape a launch mishap. When the ball-shaped capsule returned to the atmosphere at the end of the mission, it automatically assumed the correct re-entry attitude because it was weighted forward of the geometric centre. As air pressure built up, it rolled to the correct heading.







Vostok Ground Track

The path followed by Lt Yuri Gagarin in Vostok 1 on 12 April 1961. Launched from the Baikonur cosmodrome in Central Asia at 0907hr Moscow Time, Gagarin made one circuit of the Earth in 108 minutes, landing inside the spherical re-entry capsule near the village of Smelovaka, near Saratov.

Launch Vehicles

Left: Vostok 2½ stage rocket was developed from the Soviet Union's first intercontinental ballistic missile. Complete with spacecraft, it stood 125•9ft (38•4m). **Below:** Mercury-Atlas, also based on a modified ICBM, had an overall length of 95•3ft (29•0m). Both employed liquid oxygen and kerosene as propellants.

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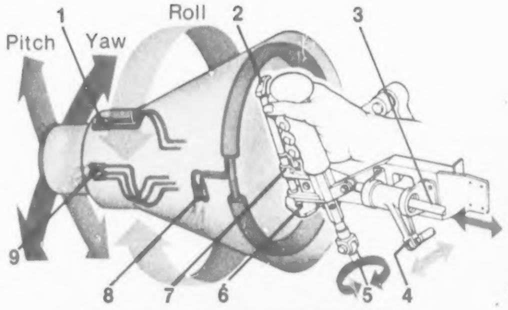
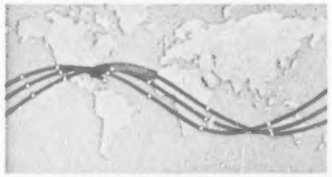
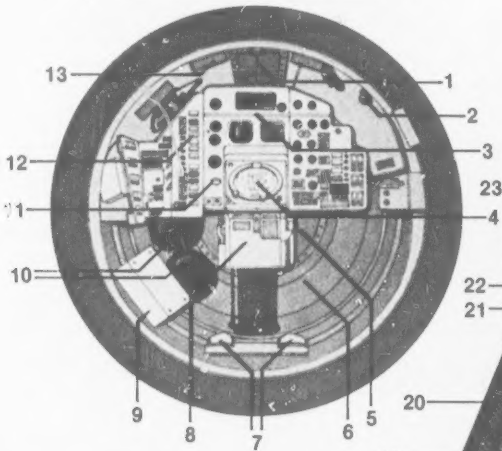
Mercury Flight Control
1 Pitch thrusters.
2 Lock pin.
3 Pitch control linkage.
4 Roll control linkage.
5 Yaw control linkage.
6 Locked position.
7 Trigger.
8 Roll thrusters.
9 Yaw thrusters.

Compared with the highly computerised systems used in today's spacecraft. The Mercury astronauts had only basic instrumentation and were encouraged to use manual controls. This drawing shows the action of the three-axis stick which the astronaut used to achieve control in pitch yaw and roll. Control actions released gas from appropriate thrusters on the spacecraft. When problems arose with the automatic attitude system. John Glenn switched to manual control to fly *Friendship 7*.



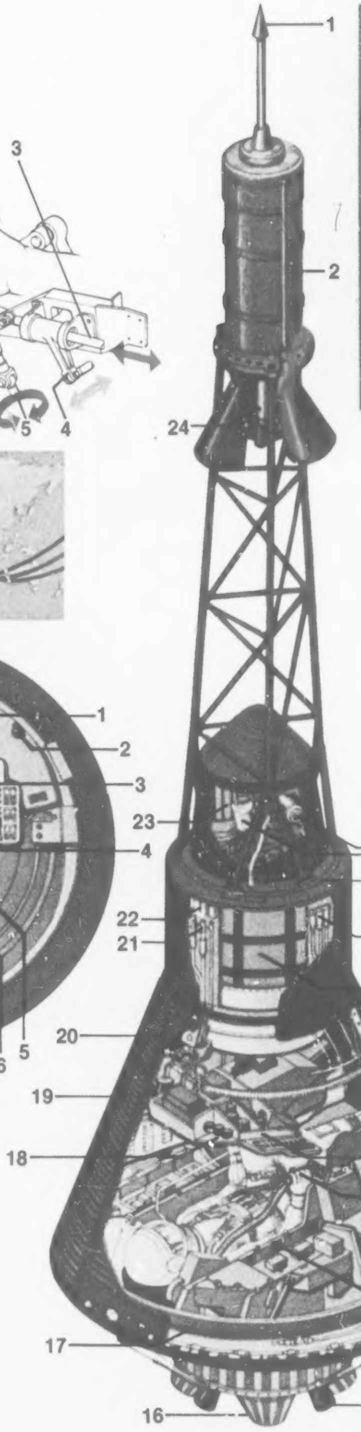
Mercury Ground Track
The path followed by Col. John Glenn after his launching from Cape Canaveral, Florida on 20 February 1962. Black spot represents the pre-staging abort zone: hatched area the abort zone following booster separation. White spots represent preferred contingency landing places from orbit.

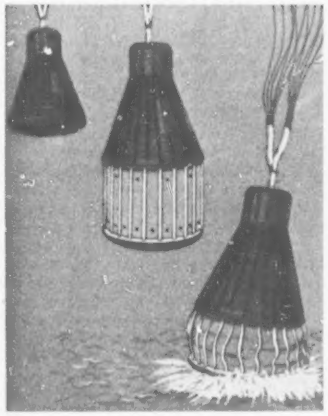




Mercury Cabin Arrangement
1 Astronaut's window.
2 Hatch release initiator.
3 Main instrument consoles.
4 Periscope display.
5 Escape hatch.
6 Small pressure bulkhead.
7 Astronaut's toe guards.
8 Map and chart kit.
9 Tape recorder.
10 Nitrogen bottles.
11 Astronaut observer camera.
12 Left console.
13 Flood lights.

This is the layout of the Mercury cabin in which John Glenn was launched from Cape Canaveral, Florida The astronaut was tightly wedged into the capsule and so all the instrument displays were designed to be easily visible, while the fly-by-wire and abort controls were readily to hand. He circled the Earth three times in a flight lasting 4 hours 55 minutes and 23 seconds, splashing down in the Atlantic about 210 miles (338km) northwest of San Juan, Puerto Rico. The later manned Mercury flights were: MA 7 (Scott Carpenter); MA 8 (Walter Schirra); MA 9 (Gordon Cooper). A 3-day MA 10 mission was finally turned down. It is interesting to note that while John Glenn's mission lifted off some 22 months late, Cooper's flight took place only 4 months after the decision to go ahead with it. Total cost of the programme was $392,100,100.





Mercury Splashdown
When the capsule returned to Earth it was first braked by drogue parachute. The main ring-sail parachute opened in a reefed condition, then inflated fully. A landing bag deployed ready for splashdown. This involved detaching the heat shield which dropped down 4ft(1·2m) pulling out a perforated skirt of rubberised glassfibre. This served as an air-cushion to reduce the landing shock. Immediately after landing, the main parachute was automatically disconnected and the capsule had sufficient buoyancy to float upright in the water. The astronaut waited inside until retrieved by a naval vessel.

Mercury Capsule
1 Aerodynamic "spike"
2 Escape rocket with three angled nozzles.
3 Infra-red horizon sensors.
4 Aerodynamic fairing.
5 Yaw thrusters.
6 Main and reserve 63ft (19·2m) diameter ring-sail parachutes.
7 Periscope.
8 Double-walled pressure cabin.
9 Instrument panels.
10 Three-axis attitude controller *(see above left)*.
11 Roll thrusters.
12 Form-fitting couch and restraints.
13 Ablative heat-shield.
14 Retro-rocket restraint strap.
15 Separation rockets.
16 Retro-rockets.
17 Hydrogen peroxide tank.
18 Abort control.
19 Skin shingles.
20 Titanium top-hat stringer.
21 Pitch thrusters.
22 Hydrogen peroxide bottles.
23 6ft (1·8m) diameter conical ribbon drogue parachute.
24 Tower separation rockets.

In this drawing the astronaut's tight fit in the pressurized capsule is clearly illustrated. The escape tower was designed to pull the capsule clear of the launch vehicle in the event of a mishap on the launch pad or after take-off. It jettisoned from the rocket when a safe altitude had been reached, after separation of the boost engines. During re-entry the heat shield was subjected to a maximum temperature of about 1,650°C at an altitude of 25 miles (40.2km) as the capsule moved at some 15,000mph

Technical Data
Overall height (including escape tower) and aerodynamic spike): 26ft (7·9m). Width (across the heat shield): 74·5in (189cm). Weight at lift-off (including escape tower): 4,265lb (1,934kg). Weight in orbit: 2,987lb (1,355kg). Weight at splashdown: 2,493lb (1,130kg).*
*Figures refer to the MA 6.

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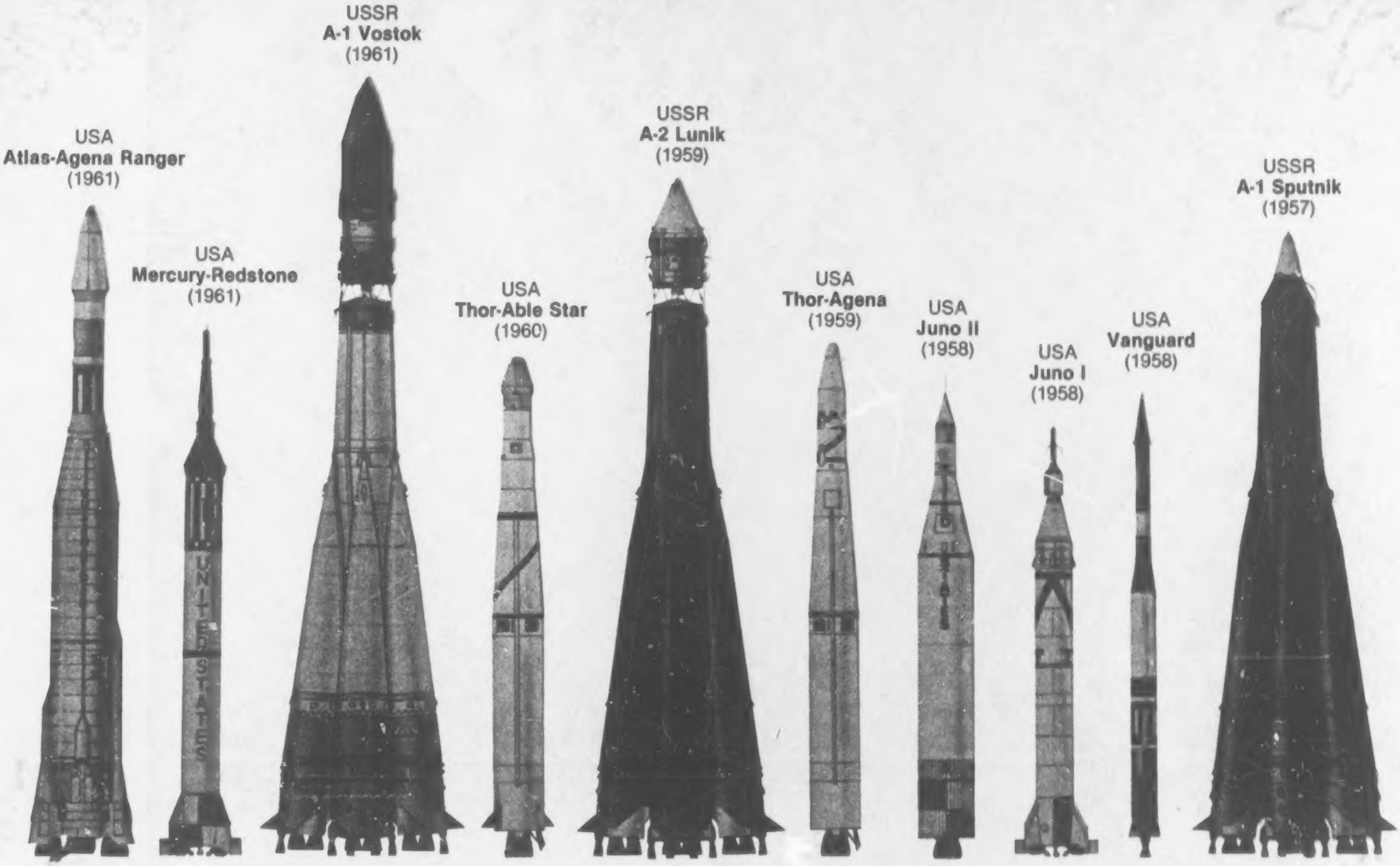
USA
Atlas-Agena Ranger
(1961)
USA
Mercury-Redstone
(1961)
UNITED STATES
USSR
A-1 Vostok
(1961)
USA
Thor-Able Star
(1960)
USSR
A-2 Lunik
(1959)
USA
Thor-Agena
(1959)
USA
Juno II
(1958)
USA
Juno I
(1958)
USA
Vanguard
(1958)
USSR
A-1 Sputnik
(1957)

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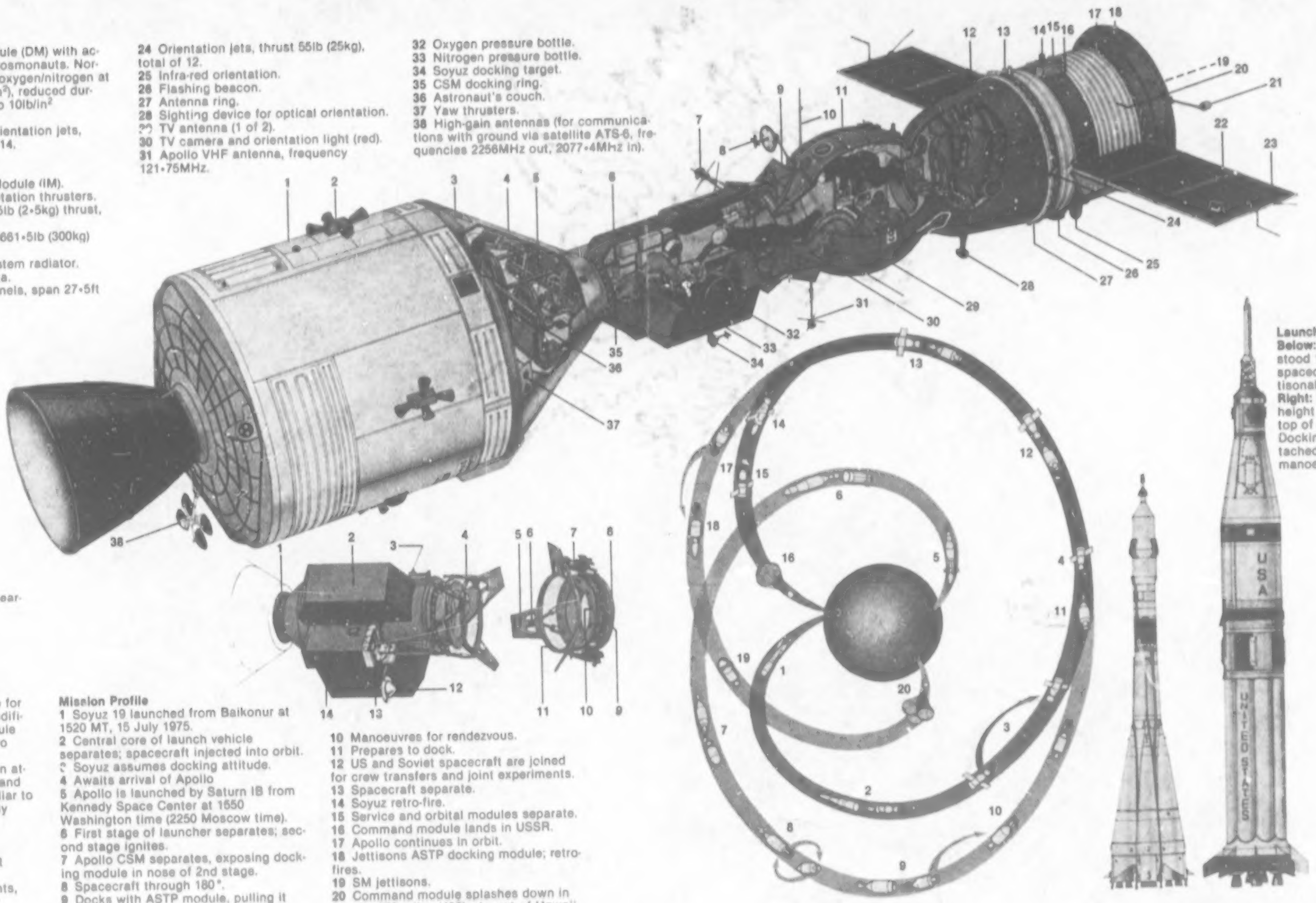
SEE FOLDOUT NO 1-2

ASTP Spacecraft in Docked Configuration

1 Apollo Service Module (SM) with bell-shaped engine nozzle. Contained propellants, fuel cells, oxygen and other supplies and equipment.
2 Reaction control quad.
3 Pitch control thrusters.
4 Apollo Command Module (CM) with accommodation for three astronauts. Cabin atmosphere pure oxygen at 5lb/in^2 (0•35kg/cm^2).
5 Control consoles.
6 Docking Module (DM) which cosmonauts/astronauts entered to acclimatise to different atmospheres before entering the other ship.
7 Apollo VHF antennas (frequency 121•75MHz).
8 Docking target.
9 Guide (1 of 3).
10 VHF antenna.
11 Soyuz Orbital Module used by crew for work and rest.
12 Soyuz Descent Module (DM) with accommodation for two cosmonauts. Normal cabin atmosphere oxygen/nitrogen at about 14•7lb/in^2(1kg/cm^2), reduced during period of docking to 10lb/in^2 (0•7kg/cm^2).
13 Soft-docking and orientation jets, thrust 22lb(10kg), total 14.
14 Flashing beacon.
15 Solar sensor.
16 Soyuz Instrument Module (IM).
17 Approach and orientation thrusters.
18 Orientation jets, 5•5lb (2•5kg) thrust, total 12.
19 Manoeuvre engine, 661•5lb (300kg) thrust.
20 Thermal control system radiator.
21 Rendezvous antenna.
22 Extensible solar panels, span 27•5ft (8•37m).
23 Telemetry antenna.
24 Orientation jets, thrust 55lb (25kg), total of 12.
25 Infra-red orientation.
26 Flashing beacon.
27 Antenna ring.
28 Sighting device for optical orientation.
29 TV antenna (1 of 2).
30 TV camera and orientation light (red).
31 Apollo VHF antenna, frequency 121•75MHz.
32 Oxygen pressure bottle.
33 Nitrogen pressure bottle.
34 Soyuz docking target.
35 CSM docking ring.
36 Astronaut's couch.
37 Yaw thrusters.
38 High-gain antennas (for communications with ground via satellite ATS-6, frequencies 2256MHz out, 2077•4MHz in).



Docking Module

1 CSM docking ring.
2 O_2 and N_2 tank cover (1 of 2).
3 VHF-FM antenna (1 of 3).
4 Attenuators.
5 Guide (1 of 3).
6 Capture latch (1 of 3).
7 Attenuator (1 of 6).
8 Tunnel interface.
9 Cable retract system motors and gearbox.
10 Structural latches.
11 Guide ring (extended).
12 Soyuz docking target.
13 Multiple operation door.
14 UV spectrometer.

Making Apollo and Soyuz compatible for the space docking involved many modifications. In particular a Docking Module had to be introduced between the two craft in which cosmonauts and astronauts could acclimatise to cabin atmospheres of different composition and pressures to avoid the "bends" familiar to deep sea divers ascending too rapidly from the ocean depths.

Technical Data

Length of cylindrical chamber: 10•3ft (3•15m). Maximum diameter: 4•7ft (1•42m). Total weight with experiments, stowage, fluids and docking system: 7,390lb (5,907kg).

Mission Profile

1 Soyuz 19 launched from Baikonur at 1520 MT, 15 July 1975.
2 Central core of launch vehicle separates; spacecraft injected into orbit.
3 Soyuz assumes docking attitude.
4 Awaits arrival of Apollo
5 Apollo is launched by Saturn IB from Kennedy Space Center at 1550 Washington time (2250 Moscow time).
6 First stage of launcher separates; second stage ignites.
7 Apollo CSM separates, exposing docking module in nose of 2nd stage.
8 Spacecraft through 180°.
9 Docks with ASTP module, pulling it free.
10 Manoeuvres for rendezvous.
11 Prepares to dock.
12 US and Soviet spacecraft are joined for crew transfers and joint experiments.
13 Spacecraft separate.
14 Soyuz retro-fire.
15 Service and orbital modules separate.
16 Command module lands in USSR.
17 Apollo continues in orbit.
18 Jettisons ASTP docking module; retro-fires.
19 SM jettisons.
20 Command module splashes down in Pacific 270 miles (432km) west of Hawaii.

Launch Vehicles

Below: The 2½ stage Soyuz launcher stood 161•75ft (49•3m) tall. The spacecraft was concealed within the jettisonable nose shroud.
Right: Saturn IB which had an overall height of 224ft (68•3m). Concealed in the top of the S-IVB second stage was the Docking Module which had to be detached in flight during a transposition manoeuvre (see Mission Profile 9).

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SEE FOLDOUT NO 3-4

Graphic Comparison of Soviet and U.S. Space Vehicles

NOTE: All illustrations in this section are adapted from "Space Technology," Salamander
Books of London, England. ©198 Crown Publishers, Inc., New York.

J952-67
①

1

USSR
A-2-e Mars/Venus
(1961)
USSR
B-1 Cosmos
(1962)
USA
Mercury-Atlas
(1962)
USSR
A-2 Voskhod
(1964)
USSR
C-1 Cosmos
(1964)
USA
Gemini-Titan
(1964)
France
Diamant A
(1965)
USA
Delta E
(1965)
USSR
D-1 Proton
(1965)
USA
Titan IIIC
(1965)
USA
Titan IIIB-Agena
(1966)
USA
Saturn IB
(1966)
USSR
A-2 Soyuz
(1967)
USSR
F-1-r FOBS
(1967)
USA
Saturn V Apollo
(1967)
USSR
F-1-m SIS
(1967)
USSR
G-1-e "Super Booster"
(1969)
UNITED STATES
USA
U S AIR FORCE
feet
100
90
80
70
60
50
40
30
20
10
0
metres
30
20
10
0

Note:
The dates in parentheses normally refer to first launch. Where a second date is given the illustration depicts a launcher that is part of a family of vehicles that has been operated and modified over a period of years. Because of the lack of officially released information, some details on the later Russian and Chinese rockets are speculative.

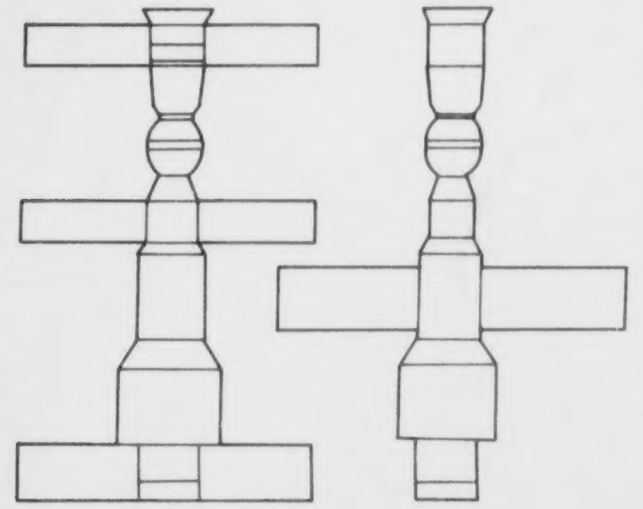
J952-67
(2)

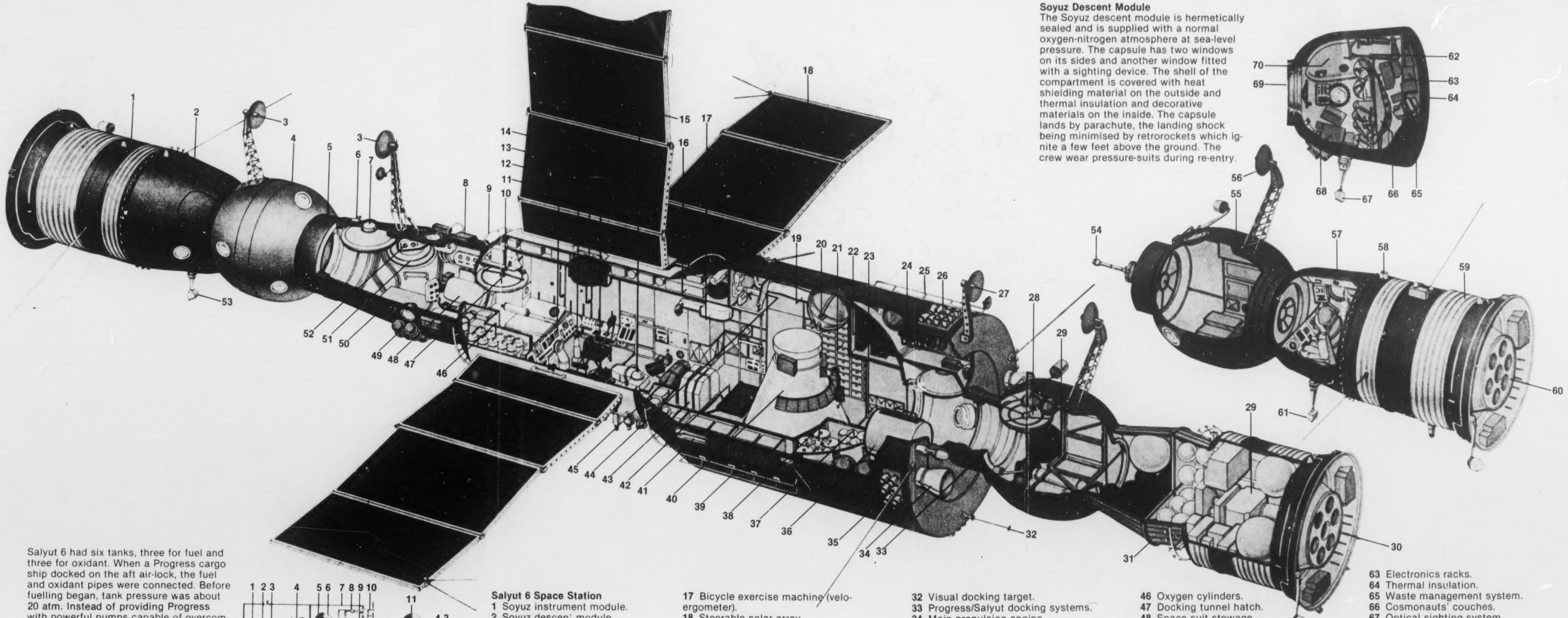
2

USSR
D-1-e Zond
(1968)
France
Diamant B
(1970)
Japan
Lambda-4S-5
(1970)
China-1
CSL-1 Long March 1
(1970)
United Kingdom
Black Arrow (Prospero)
(1971)
USA
Titan IIID
(1971)
USSR
D-1 Salyut 1
(1971)
Japan
Mu-4s
(1971)
ELDO
Europa II
(1971)
USA
Scout
(1972/1960)
USA
Saturn V Skylab
(1973)
USA
Delta 2914
(1974)
USA
Titan IIIE-Centaur
(1974)
Japan
Mu-3C
(1974)
USA
Delta 3914
(1975)
France
Diamant BP4
(1975)
Japan
N-I
(1975)
China
CSL-2 FB-1
(1975)
USA
Atlas E/F
(1977/1961)
Japan
Mu-3H
(1977)
USA
Atlas-Centaur
(1977/1962)
India
SLV-3
(1979)
ESA
Ariane I
(1979)
USA
Space Shuttle
(1981)
USA
Titan 34D
(1981)
USA
Delta 3920
(1982)
UNITED STATES
USA

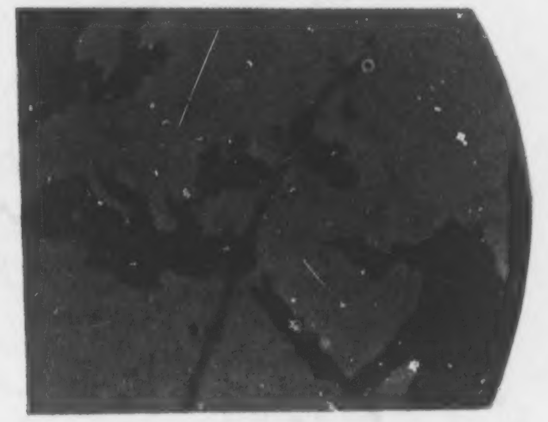
J952-67
③

Salyuts 1 and 4 compared
When Salyut 1 (below left) was introduced in 1971, the station had two sets of solar arrays which extended like wings fore and aft. In 1974, Salyut 4 (below right) revealed a new distribution of solar panels in which three arrays—two horizontal, one vertical—were centrally disposed on the station. They were mounted on bearings and rotated to face the Sun in response to "solar gages." Only one docking port was provided for visiting Soyuz ferries on both these vehicles. Ferry craft docking with Salyut 4 dispensed with solar panels, being able to recharge internal chemical batteries from the space station's own solar power supply.





Soyuz Descent Module
The Soyuz descent module is hermetically sealed and is supplied with a normal oxygen-nitrogen atmosphere at sea-level pressure. The capsule has two windows on its sides and another window fitted with a sighting device. The shell of the compartment is covered with heat shielding material on the outside and thermal insulation and decorative materials on the inside. The capsule lands by parachute, the landing shock being minimised by retrorockets which ignite a few feet above the ground. The crew wear pressure-suits during re-entry.

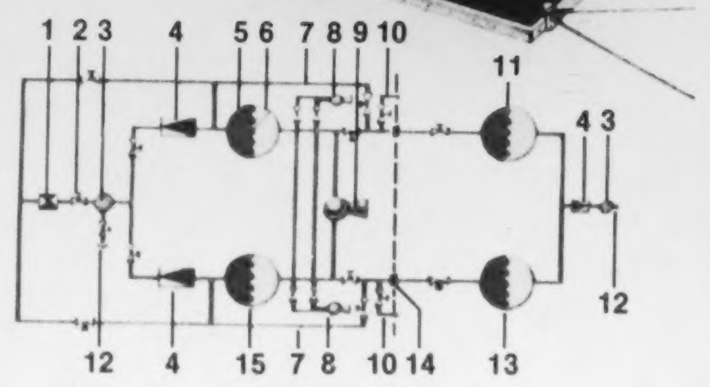


Soyuz Landing Profile
1 Entry into atmosphere.
2 RF blackout begins.
3 RF blackout ends.
4 Landing area.

The Soviet Union normally recovers its manned spacecraft in an area just north of Baikonur in the Republic of Kazakhstan. Returning from an orbit inclined at 51•6° to the equator, the re-entry module makes its approach over North Africa, the eastern end of the Black Sea and the western end of the Caspian. The capsule is tracked by radar and an on-board radio beacon directs recovery forces.

Progress/Salyut Refuelling System
1 Compressor.
2 Valves and vents.
3 High pressure sphere (propellant feed system).
4 System for introduction and removal of compressed air into and out of spherical tanks.
5 Fuel tank in Salyut (1 of 3).
6 Diaphragm.
7 Air lines to "blow off" residual propellant from pipes.
8 Control thrusters.
9 Manoeuvre engine.
10 Lines leading to exterior valves for venting residual propellants.
11 Fuel tank in Progress (1 of 2).
12 Turncock for control of compressed air.
13 Oxidant tank in Progress (1 of 2).
14 Hydraulic connectors.
15 Oxidant tank in Salyut (1 of 3).

Salyut 6 had six tanks, three for fuel and three for oxidant. When a Progress cargo ship docked on the aft air-lock, the fuel and oxidant pipes were connected. Before fuelling began, tank pressure was about 20 atm. Instead of providing Progress with powerful pumps capable of overcoming this pressure, Soviet designers preferred to pump the nitrogen pressurizing gas back into the supply bottles before refuelling operations began, flushing out the tanks with helium. Use was made of a 1kW, three-phase electric motor powered by the station's solar arrays via an AC converter. Then, propellants stored in the cargo ship at a pressure of 2•5 to 3•0 atm could be transferred to Salyut at pressures of up to 7 atm.



Salyut 6 Space Station
1 Soyuz instrument module.
2 Soyuz descent module.
3 Rendezvous antenna.
4 Soyuz orbital module.
5 Docking interface.
6 External TV camera mounting.
7 Docking hatch.
8 External thermal control panels.
9 EVA handrails.
10 TV camera.
11 Instrument panel.
12 Control system.
13 Solar panel rotary drive.
14 Cosmonauts' seats.
15 Water storage.
16 Electronics racks.
17 Bicycle exercise machine (velo-ergometer).
18 Steerable solar array.
19 Sleep restraint.
20 Refuse ejection airlock.
21 Food lockers.
22 Dust filter.
23 Sanitary facilities.
24 Propulsion engine and attitude thrusters control group.
25 EVA handrail.
26 Attitude control thrusters.
27 Rendezvous antenna.
28 Aft hatches.
29 Fuel, food, water and oxygen supplies.
30 Propulsion system.
31 Progress service module.
32 Visual docking target.
33 Progress/Salyut docking systems.
34 Main propulsion engine.
35 Attitude control thrusters.
36 Propellant tank.
37 Water storage.
38 Refuse containers.
39 EVA handrails.
40 BST 1 M submillimeter telescope and instrument module with cryogenic cooling unit (top left) and 12.x optical sight (right of conical housing).
41 Launch shroud attachment.
42 Close-loop running track.
43 MKF-6M multispectral camera.
44 Zero-gravity weighing machine.
45 Vacuum cylinder.
46 Oxygen cylinders.
47 Docking tunnel hatch.
48 Space suit stowage.
49 Compressed air bottles.
50 Docking tunnel.
51 EVA hatch.
52 Airlock controls.
53 Optical sighting system.
54 Soyuz docking probe.
55 Orbital module.
56 Rendezvous antenna.
57 Command module/re-entry module.
58 Attitude thrusters.
59 Service module.
60 Propulsion system.
61 Optical sighting system.
62 Couch support.
63 Electronics racks.
64 Thermal insulation.
65 Waste management system.
66 Cosmonauts' couches.
67 Optical sighting system.
68 Instrument panels.
69 Docking hatch.
70 Main parachute container.

Salyut 6 served the Soviet Union superbly for over 3 years, and Soviet faith in the pursuit of a manned space station programme was underlined by the Soyuz T-3 flight in late November 1980. This was the first three man mission since the ill-fated Soyuz 11 accident in which the crew died during re-entry. In the T-3, the crewmen were able to wear pressure suits. The cosmonauts Lt-Col Leonid Kizim (commander), Oleg Makarov (flight engineer) and Gennady Strekalov (research cosmonaut) docked with Salyut 6 on 28 November with the express intention of carrying out extensive repair work. Their tasks included repairing a complex hydraulic system; incorporating pumps in Salyut's fluid-based temperature control system which involved managing liquids in zero-g; programming a timing device in the control system; replacing telemetry components; feeding the in-orbit refueling system and overhauling part of the power supply. Special tools were taken aloft for these purposes. The crew also used the docked Progress 11 to raise the Salyut cluster into a higher orbit.

Technical Data
Salyut 6
Length overall: approximately 49•2ft (15m). Length with two Soyuz: exceeds 95•1ft (29m). Diameters of structural cylinders, front to back: 6•56ft (2m), 9•51ft (2•9m), 13•6ft (4•15m). Weight, without ferry attachments: 41,674lb (18,900kg). Weight, scientific equipment: 3,307lb (1,500kg). Docking ports: 1 fore, 1 aft. Solar cell panels: three each of 215•3ft^2 (20m^2). Thrust, manoeuvre engine: 661lb (300kg).

Progress
Length, docking probe to base: 26ft (7•94m). Length, face of docking assembly to base: 22•9ft (6•98m). Maximum diameter, base: 8•92ft (2•72m). Diameter, cargo compartment: 7•2ft (2•2m).
Launch weight: 15,479lb (7,020kg).
Cargo: 5,071lb (2,300kg), including up to 2,205lb (1,000kg) propellants for Salyut refuelling. Cargo section, hermetically sealed, volume: 233ft^3 (6•6m^3); 1 atm pressure; 3-30 °C temp. Duration of independent flight: 3-4 days. Duration of joint flight with orbital station: up to 30 days.
Orbit: 124-217 miles (200-350km) x 51•6°.
Approach to docking controlled by 14 x 22lb (10kg) and 8 x 2•2lb (1kg) jets.

Soyuz
Length: 26ft (7•94m) Maximum diameter: 8•92ft (2•72m).
Internal volume, descent module: 134•2ft^3 (3•8m^3). Launch weight:, 14,994lb (6,800kg).
Landing weight: 6,174lb (2,800kg).
Landing velocity, braked by retro-rockets: 10-13ft/sec (3-4m/sec). Orbit: 124-217 miles (200-350km) x 51•6°. Duration of independent flight: 3 days. Duration of joint flight with orbital station: 90 days.

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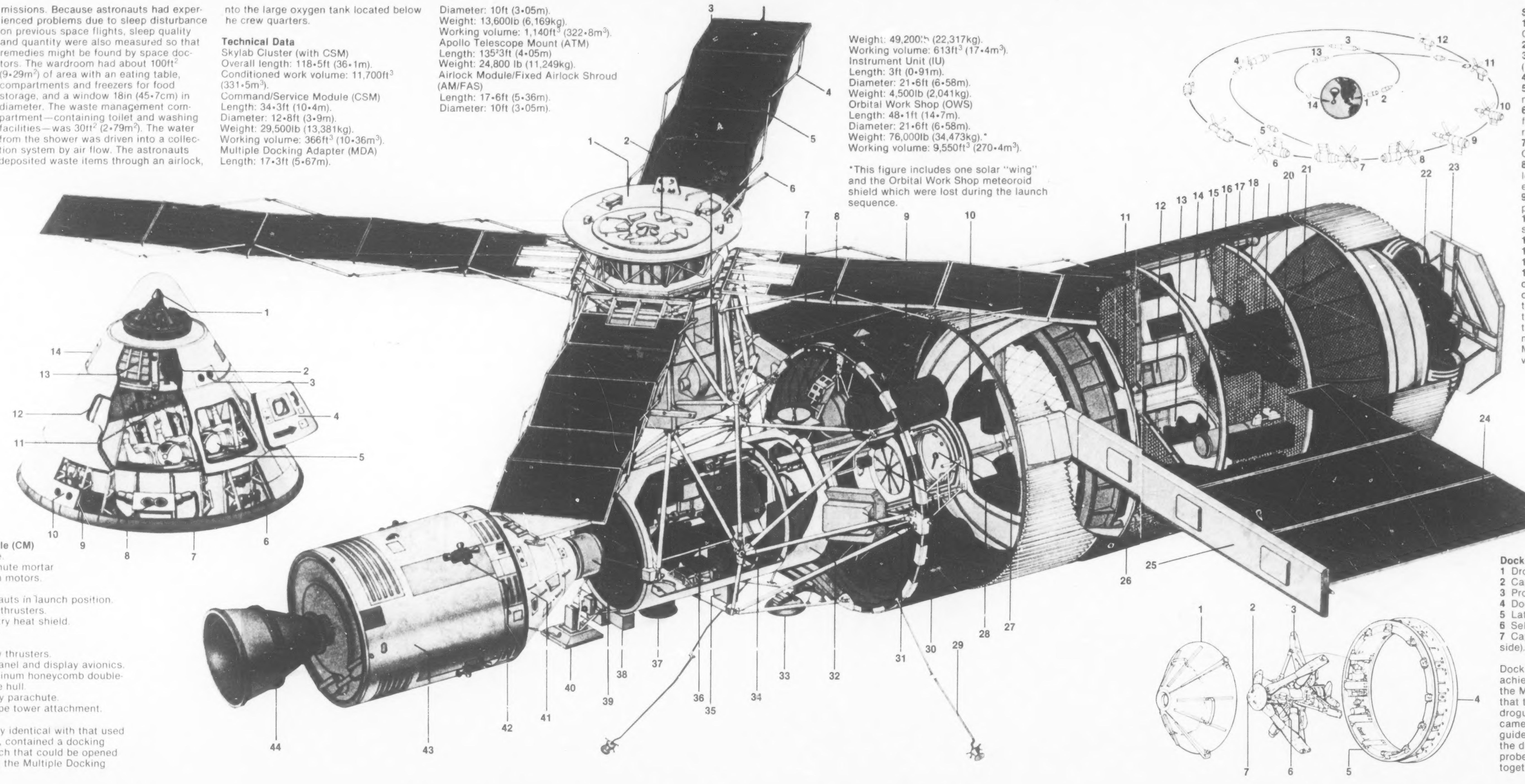
Skylab
1 Solar shield.
2 Apollo telescope sensors.
3 Battery and regulator module.
4 "Pantograph" extension linkage.
5 ATM solar panels.
6 Antenna boom.
7 Orbital workshop solar array.
8 Nitrogen tank.
9 Oxygen tanks.
10 Water tanks.
11 Stowage lockers.
12 Waste management compartment.
13 Wardroom and galley.
14 Sleep compartment.
15 Shower cabinet.
16 Rotating litter chair.
17 Control console.
18 Workshop floor grids.
19 Exercise bicycle (velo-ergometer).
20 Lower body negative pressure experiment.
21 Wastetank separation screens.
22 Attitude control nitrogen bottles.
23 Refrigeration system radiator.
24 Solar array. (Skylab is shown here in its original design configuration. In fact this panel was torn off by air pressure during the launch phase).
25 Solar panel deployment boom.
26 Micrometeoroid shield (also torn off during launch phase).
27 Cabin atmosphere distribution ducts.
28 Orbital workshop hatch.
29 Discone antennas.
30 Docking hatch.
31 Battery box.
32 Multiple Docking Adapter.
33 Microwave radiometer/ scattermeter.
34 Apollo Telescope Mount (ATM) support struts.
35 Multispectral scanner.
36 Multiple Docking Adapter workshop.
37 Radial docking port.
38 Infra-red spectrometer.
39 Axial docking hatch.
40 L-band antenna.
41 Command Module.
42 Vernier control motors.
43 Service Module.
44 Propulsion engine nozzle.

Principal Scientific Experiments:
Primary work station for conducting the solar experiments of the Apollo Telescope Mount (ATM) was in the Multiple Docking Adapter (MDA). Through a television system, the astronauts were able to see images of the Sun recorded by the telescopes. The control and display panels for the Earth resources experiments were also located in the MDA. A special airlock in the wall of the orbital workshop allowed the crew to perform special "outside" experiments. For example, a camera equipped with calcium fluoride transmission optics to pass ultra-violet light was aimed at stars in the Milky Way. Knowledge of the Earth's upper atmosphere airglow measurements were gained from UV photography from two positions inside the Workshop. One camera position was at the wardroom window.
Medical apparatus installed in Skylab included equipment for monitoring an astronaut's cardiovascular system. A slight suction applied to the lower half of the man's body placed a stress on the heart and blood vessels. Responses to this before, during and after the flight provided information on cardiovascular accommodation during long-duration space flight. In another test using a revolving litter chair (which could be adjusted to a horizontal position), the effects of weightlessness and sub-gravity conditions on astronaut perception, motion sensitivity, orientation, and balance were investigated. This helped to determine the need for artificial gravity in future space missions. Because astronauts had experienced problems due to sleep disturbance on previous space flights, sleep quality and quantity were also measured so that remedies might be found by space doctors. The wardroom had about 100ft^2 (9•29m^2) of area with an eating table, compartments and freezers for food storage, and a window 18in (45•7cm) in diameter. The waste management compartment—containing toilet and washing facilities—was 30ft^2 (2•79m^2). The water from the shower was driven into a collection system by air flow. The astronauts deposited waste items through an airlock, into the large oxygen tank located below the crew quarters.

Technical Data
Skylab Cluster (with CSM)
Overall length: 118•5ft (36•1m).
Conditioned work volume: 11,700ft^3 (331•5m^3).
Command/Service Module (CSM)
Length: 34•3ft (10•4m).
Diameter: 12•8ft (3•9m).
Weight: 29,500lb (13,381kg).
Working volume: 366ft^3 (10•36m^3).
Multiple Docking Adapter (MDA)
Length: 17•3ft (5•67m).
Diameter: 10ft (3•05m).
Weight: 13,600lb (6,169kg).
Working volume: 1,140ft^3 (322•8m^3).
Apollo Telescope Mount (ATM)
Length: 135^{2}3ft (4•05m)
Weight: 24,800 lb (11,249kg).
Airlock Module/Fixed Airlock Shroud (AM/FAS)
Length: 17•6ft (5•36m).
Diameter: 10ft (3•05m).
Weight: 49,200lb (22,317kg).
Working volume: 613ft^3 (17•4m^3).
Instrument Unit (IU)
Length: 3ft (0•91m).
Diameter: 21•6ft (6•58m).
Weight: 4,500lb (2,041kg).
Orbital Work Shop (OWS)
Length: 48•1ft (14•7m).
Diameter: 21•6ft (6•58m).
Weight: 76,000lb (34,473kg).*
Working volume: 9,550ft^3 (270•4m^3).

*This figure includes one solar "wing" and the Orbital Work Shop meteoroid shield which were lost during the launch sequence.



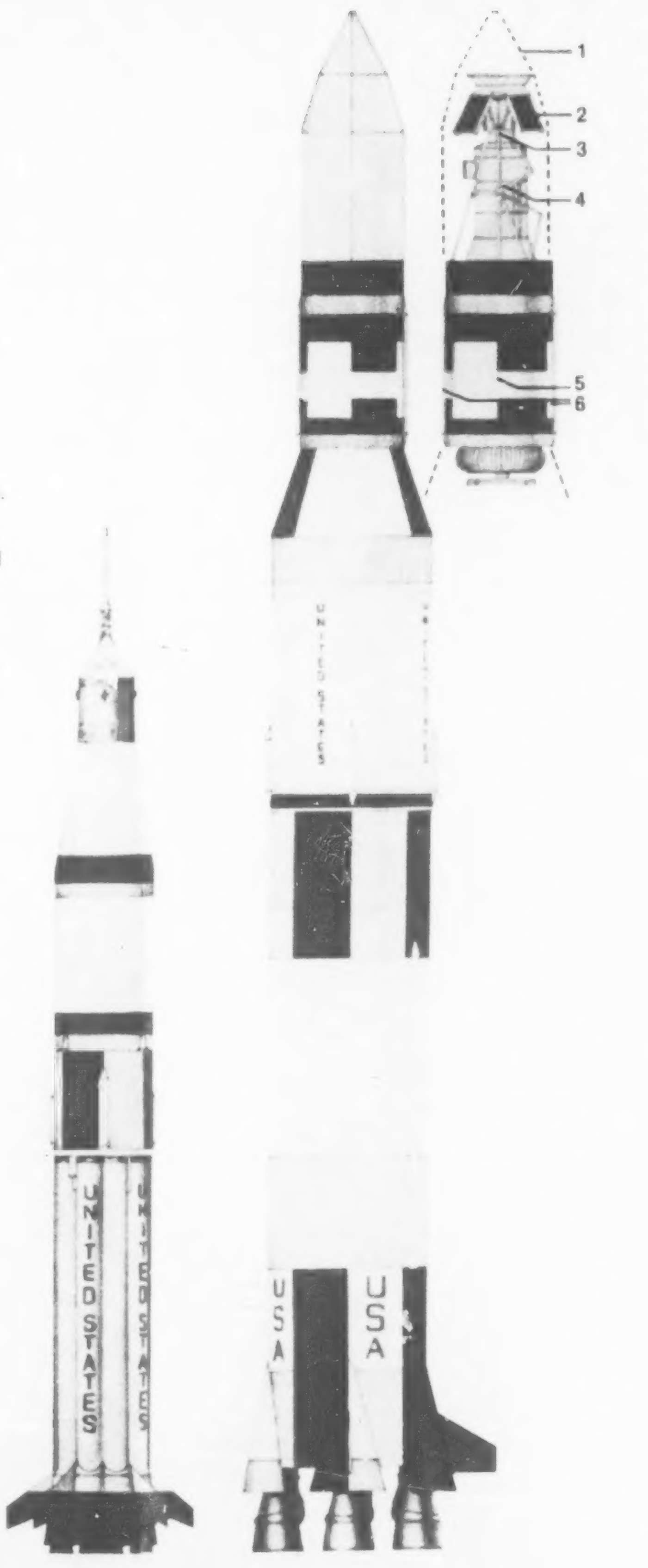
Command Module (CM)
1 Docking probe.
2 Drogue parachute mortar
3 Negative pitch motors.
4 Hatch cover.
5 Three astronauts in launch position.
6 Positive pitch thrusters.
7 Ablative re-entry heat shield.
8 Roll thrusters.
9 Water tank.
10 Negative yaw thrusters.
11 Instrument panel and display avionics.
12 Bonded aluminum honeycomb double-skinned pressure hull.
13 Main recovery parachute.
14 Launch escape tower attachment.

The CM, basically identical with that used on Apollo flights, contained a docking tunnel and a hatch that could be opened after linking with the Multiple Docking Adapter.

Skylab: Docking Profile
1 Launch of third crew from Cape Canaveral, Florida.
2 S-IB stage separates.
3 S-IVB boost to 93 × 138 miles (150 × 222km) orbit.
4 CSM/S-IV separation.
5 CSM rendezvous manoeuvres to 270 miles (434km).
6 Skylab orients to Z-axis local vertical for CSM rendezvous; docking lights and ranging system on.
7 Skylab orients to solar inertial attitude. CSM docks with Skylab.
8 Combined vehicles orient to Z-axis local vertical attitude for Earth resources experiments.
9 Orient to solar inertial attitude; complete 84-day mission.
10 Skylab prepared for closedown and storage. Crew transfer to CSM.
11 CSM undocks.
12 CSM retro-thrust starts return to Earth.
13 CM/SM separate.
14 CM re-enters atmosphere. Parachutes deploy; splashdown in Pacific. At the end of the mission the astronauts prepared the Skylab cluster for unmanned operation, transferred to the CSM and separated from the station. A deceleration manoeuvre executed by firing the Service Module engine, caused the CSM to lose velocity and re-enter the atmosphere.

Docking Unit (CSM)
1 Drogue assembly (MDA).
2 Capture latches.
3 Probe assembly (CSM).
4 Docking ring (CM).
5 Latch assemblies.
6 Self-locking extension latch.
7 Capture latch release handle (MDA side).

Docking of the CSM with Skylab was achieved by manoeuvring close enough to the Multiple Docking Adapter (MDA) so that the probe of the CM engaged a drogue on the MDA. When the probe came into contact with the drogue, it was guided into the socket at the bottom of the drogue. Three capture latches in the probe head then held the two vehicles together.



Skylab Launch Vehicles
1 Launch protective cover.
2 ATM solar panels (folded configuration).
3 Apollo Telescope Mount in launch position.
4 Multiple Docking Adapter (MDA).
5 Orbital workshop.
6 Workshop solar panels (stowed configuration).

Left: two-stage Saturn V which launched the Skylab space station. The ATM and solar "wings" were stored within the jettisonable nose shroud. The vehicle stood 333•7ft (101•71m) tall and had a maximum diameter of 33ft (10•06m). Launch weight about 6,222,000lb (2,821,770kg). Boost acceleration limit increased from 4 to 4•7g because vehicle was unmanned. The Skylab spacecraft was stacked on the Saturn V launch vehicle in the Vehicle Assembly Building at Kennedy Space Center and was transported to Launch Pad-39A by a large crawler transporter.

Far left: Saturn IB which carried the astronauts into orbit to dock with Skylab. The vehicle stood 224ft (68•3m) tall complete with Apollo CSM and escape tower. Launch weight about 1,200,000lb (589,570kg). Each of the eight H-1 first stage engines was uprated from 200,000lb (90,703kg) to 205,000lb (92,970kg) thrust to enhance payload capability.

Skylab/Salyut 6 Scale Comparison
America's Skylab space station, more than four times heavier and considerably larger than the Soviet Union's Salyut was made from the S-IVB third stage of a Saturn V moon rocket. The hydrogen fuel tank was modified to provide the crew quarters and experiment workshop. The latter was big enough to allow astronauts wearing the Astronaut Manoeuvring Unit (AMU) to conduct flight trials inside the station.